Y3T25.2 C91/4/act.9

SEP 22 1987

C M C P

ORIGINAL

CUMBERLANDIAN MOLLUSK CONSERVATION PROGRAM

ACTIVITY 9:
Selection of Transplant Sites and
Habitat Characterization

Office of Natural Resources and Economic Development
Tennessee Valley Authority
Knoxville, Tennessee 37902

TVA/ONRED/AWR-86/23

COMPLETED

ORIGINAL

TENNESSEE VALLEY AUTHORITY

Office of Natural Resources and Economic Development

Division of Air and Water Resources

CUMBERLANDIAN MOLLUSK CONSERVATION PROGRAM

Activity 9:

Selection of Transplant Sites and Habitat Chacterization

Prepared by

John J. Jenkinson
John H. Heuer

Knoxville, Tennessee

February 1986

TABLE OF CONTENTS

	Page
List of Tables	ii
List of Figures	vi
Introduction	1
Selection of Study Reaches	1
Selection of Transplant Sites	4
Similarity Indices	8
Quantitative Biotic Similarities	10
Quantitative Physical/Chemical Similarities	11
Discriminant Function Analysis	14
Transplant Site Selection	18
Habitat Characterization	26
Examination of Ecological Factors	29
Physical Factors	30
Chemical Factors	31
Biological Factors	37
Composite Analysis	38
Potential Bias	41
Characterization	43
Tables	50
Figures	86
Literature Cited	90
Appendix A. Cumberlandian Mollusk Conservation Program Designated Study Reaches	92
Appendix B. Summaries of Physical Factors Used in Correlation and Partial Correlation Analyses	98
Appendix C. Summaries of Chemical Factors Used in Correlation and Partial Correlation Analyses	103
Appendix D. Summaries of biological factors Used in Correlation and Partial Correlation Analyses	115

LIST OF TABLES

Table		Page
1	Prospective stream reaches to be evaluated for selection as designated study reaches for the Cumberlandian Mollusk Conservation Program.	50
2	Criteria for the evaluation of potential Cumberlandian Mollusk Conservation Program designated study reaches and the relative weights assigned to each	51
3	Matrix evaluation of potential Cumberlandian Mollusk Conservation Program designated study reaches.	52
4	The twenty stream reaches most likely to be suitable for use as designated study reaches in the Cumberlandian Mollusk Conservation Program arranged in order of their evaluation scores	54
5	Tabulation of the Jaccard Coefficients of similarity for qualitative biotic data between Lillards Mill and the other CMCP designated study reaches	55
6	Tabulation of the Jaccard Coefficients of similarity for qualitative biotic data between Kyles Ford and the other CMCP designated study reaches	56
7	Tabulation of the Euclidean distances of dissimilarity for quantitative biotic data between Lillards Mill and the other CMCP designated study reaches	57
8	Tabulation of the Euclidean distances of dissimilarity for quantitative biotic data between Kyles Ford and the other CMCP designated study reaches	58
9	Tabulation of the Euclidean distances of dissimilarity for quantitative abiotic data between Lillards Mill and the other CMCP designated study reaches	59

LIST OF TABLES

(Continuted)

Table		Page
10	Tabulation of the Euclidean distances of dissimilarity for quantitative abiotic data between Kyles Ford and the other CMCP designated study reaches	59
11	Standardized canonical discriminant function coefficients for selected hyrologic variables	60
12	Standardized canonical discriminant function coefficients for selected physical/chemical variables	60
13	Standardized canonical discriminant function coefficients for selected physical/chemical variables	61
14	Matrix of correlation coefficients derived from comparisons of biotic variables within previously established groups of CMCP designated study reaches	62
15	Biotic variable means, F statistics, and significance levels for the four *a priori* groups of CMCP designated study reaches	63
16	Standardized canonical discriminant functon coefficients for selected summary biotic variables	64
17	Summary results of discriminant function analysis	65
18	Final rankings of non-group 1 designated study reaches	66
19	Relative ranking of CMCP study reaches based upon species richness of the freshwater mussel fauna in the inclusive 40-mile stream section.	67
20	Pearson correlation coefficients among mussel PCA factors and physical factors of the study reaches	68
21	Partial correlation coefficients for selected physical factors to mussel PCA factors controlled for the combined effect of drainage area and average flow	69

LIST OF TABLES

(Continued)

Table		Page
22	Pearson correlation coefficients for chemical factors and mussel PCA factors	70
23	Pearson correlation coefficients among mussel PCA factors and hardness group factors	71
24	Partial correlation coefficients for selected chemical factors in the hardness group to mussel PCA factors controlled for the effect of alkalinity	72
25	Partial correlation coefficients for selected hardness group factors controlled for the effect of sulfate	72
26	Pearson correlation coefficients among mussel PCA factors and metals group factors for the full 11-month sampling period and the summer-fall and winter-spring subsets	73
27	Partial correlation coefficients for selected metals group factors to mussel PCA factors controlled for the effect of total iron.	74
28	Person correlation coefficients among mussel PCA factors and "others" group factors for the full 11-month sampling period and the summer-fall and winter-spring subsets	75
29	Partial correlation coefficients for selected chemical factors in the "others" group to mussel PCA factors controlled for the effect of organic nitrogen	76
30	Pearson correlation coefficients among mussel PCA factors and biological factors	77

LIST OF TABLES

(Continued)

Table		Page
31	Partial correlation coefficients for selected biological factors to mussel PCA factors controlled for the effect of zooplankton taxa	78
32	Ecological factors which yielded significant correlations with mussel species richness (PCA) factors	29
33	Pearson correlation coefficients among mussel factors and key environmental factors during the summr-fall season (May and July-October)	80
34	Pearson correlation coefficients among mussel factors and key environmental factors during the winter-spring season (November-April)	81
35	Partial correlation coefficients for key factors during the summer-fall season to mussel PCA factors controlled for the separate effects of drainage area, alkalinity, and sulfate	82
36	Partial correlation coefficients for key factors during the winter-spring season to mussel PCA-factors controlled for the separate effects of drainage area alkalinity and sulfate	83
37	Pearson correlation coefficients for key water quality factors with the mussel factors excluding data from both Powell River study reaches	84
38	Summary of relationships of environmental factors to mussel habitat characterization	85

LIST OF FIGURES

Figure		Page
1	Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discriminant functions of the analysis of hydrologic data . . .	86
2	Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discriminant functions of the analysis of water quality data	87
3	Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discriminent functions of the analysis of hydrologic and water quality data combined	88
4	Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discrminant functions of the analysis of biotic data (excluding mussel information)	89

INTRODUCTION

This report is one of nine in a series that will document the accomplishments of the research phase of the Tennessee Valley Authority (TVA) Cumberlandian Mollusk Conservation Program (CMCP). This report describes the selection process and the composite analysis of 15 short reaches of free flowing streams in which the physical, limnological, botanical, and zoological components were examined. The purposes of this summary report--and of the entire research phase of the CMCP--are to identify combinations of environmental conditions which occur in the study areas that support populations of Cumberlandian freshwater mussels and to select transplant sites which could support populations of selected Cumberlandian mussel species, especially Conradilla caelata, once they were (re)introduced. This report is divided into three major sections (selection of study reaches, selection of transplant sites, and habitat characterization) two of which appear to fall in reverse order. Chronologically, transplant sites for the birdwing pearly mussel, Conradilla caelata, were selected before the characterizaton of mussel habitat could be completed. Since the transplants were made based upon the comparison of sites presented in that analysis, the site selection description was retained in an unmodified state.

SELECTION OF STUDY REACHES

During the initial planning phase of the Cumberlandian Mollusk Conservation Program (CMCP), it became apparent that several of the proposed activities would involve examination of stream reaches where

Cumberlandian mussels occur, as well as and other streams with potential to be transplant sites for Conradilla caelata and other species. Instead of each activity leader selecting his own study sites, it was decided to use a single group of study reaches that would meet the criteria for each planned activity; this would allow for multifactor analysis of all of the information collected.

Although the Cumberlandian freshwater mussel fauna, in general, is known from the upper reaches of both the Tennessee and Cumberland river systems, the distribution patterns of several species found in the Duck River indicate that our study efforts and transplant activities should be restricted to the Duck River system and the Tennessee River system above Muscle Shoals, Alabama. With this in mind, an initial list was prepared of all unimpounded stream reaches in this geographic area that have drainage areas larger than 150 square miles (a rough indication of minimum sustained flow). A group of TVA biologists, water quality experts, and others with general knowledge of streams in the Valley met to review this list. They eliminated streams with known impacts from pollution sources, recent channelization, urbanization, and other environmental conditions unsuitable for freshwater mussels. Thirty stream reaches were retained by this initial screening (table 1).

The attendees at this meeting also agreed that the remaining reaches would be evaluated by determining their suitability with reference to several criteria including substrate, water quality, and biological and human impacts as they relate to freshwater mussels. The criteria selected and relative weight applied to each are listed in table 2. Determination of whether a particular stream reach should receive an unsuitable rating for a criterion was based on a review of

existing records or publications available to TVA staff; no field observations of these areas were made at this time.

The matrix evaluation of the 30 stream reaches (table 3) provided a relative ranking of these areas, with low scores indicating areas suggested for selection as study reaches (table 4). Three additional factors were considered in making the final selections: (1) ensuring that an adequate number of sites where Duck River endangered species persist was involved, (2) making sure that potential transplant sites in the Duck River system were included, and (3) attempting to spread the other sites as widely as possible throughout the Tennessee River system.

Identification of the specific 650-foot study reaches occurred in May 1980 and sampling (for CMCP Activities 5-8) began in June and July 1980. By October 1980, the study reaches had been investigated in sufficient detail to realize that four of the original choices were not suitable for further study, largely because of local substrate conditions. Four alternate study reaches were chosen on the same streams in November 1980. Appendix A presents a list of the nineteen sites studied for various periods of time, the geographic and political locations of each reach, and a narrative description of the actual 650-foot stream interval.

SELECTION OF TRANSPLANT SITES

Companion reports present the methods, results, and analyses of the study reach data divided into four major components: physical habitat (Activity 5); water quality (Activity 6); macrophytes, plankton, and periphyton (Activity 7); and macrofauna (Activity 8). Each of these reports compares the designated study reaches from its own perspective, providing a full treatment of the data that were collected.

The combined summary and evaluation of these four data sets and analyses are the chief functions of this report. Two analytical approaches were used to integrate these data sets: similarity analysis and discriminant functions analysis.

Similarity Analysis

Similarity was determined using multivariate statistical approaches. Qualitative biological data (species presence/absence for each site) were analyzed using Jaccard's coefficient (Boesch, 1977). This similarity coefficient was chosen primarily because we decided to ignore negative matches in the data (when a species of interest was absent at both sites being compared). Sneath and Sokal (1973) recommend the Jaccard Coefficient in such situations. Boesch (1977) also prefers Jaccard Coefficients for instances where the researcher expects a relatively large number of shared occurrences. This was a likely situation for the CMCP study reaches because all of the areas being studied included riffle habitats and all were within the Tennessee River system. Jaccard Coefficient values range from zero--when no positive attributes are shared--to one--when both sites have identical attribute lists.

Similarity between sites based on quantitative data (species abundances and physical/chemical variables) was determined using Euclidean distance comparisons (Gower, 1967). Euclidean distance was chosen as the dissimilarity measure for quantitative data because it can be visualized in geometric terms (Sneath and Sokal 1973). Euclidean distance also has the advantage that an expected value and associated 95 percent confidence limit can be calculated if the variables are independent, and normally distributed, with zero mean and unit variance. The last two assumptions were met by standardizing CMCP data prior to analysis. Euclidean distance values may range from zero--when two sites are identical--to infinity. The expected value of average distance between two sites was calculated by Sneath and Sokal (1973) to range from 1.3 to 1.4 for numbers of species similar to those found in this study.

Euclidean distance does have certain disadvantages, however. Boesch (1977) pointed out that Euclidean distance tends to overemphasize outstanding dominance of certain species and may give an unrealistically high resemblance for sites which have few species in common, each with uniformly low abundance. In an attempt to overcome this bias for this study, all abundance values were standardized before analysis.

For both qualitative and quantitative data, similarity values were calculated separately for each biotic or physical/chemical category (i.e., zooplankton, macrobenthos, hydrology, etc.) and summed over all groups to provide a summary index of similarity. This procedure produced roughly equal weighting for each category of data.

Multiple Discriminant Function Analysis (DFA)

The second approach made use of discriminant function analysis (Gower, 1966; Blackith and Rement, 1971). Most biological applications of this technique and the associated canonical variate analysis have been concerned with taxonomic problems (Blackith and Rement, 1971; Sneath and Sokal, 1973; Casselman, et al., 1981; and Ihssen, et al., 1981); however, several researchers have successfully applied discriminant function analysis (DFA) to problems of community classification and environmental impact assessment (Goldstein and Grigal, 1972; Poole, 1974; Green, 1979; Baver, et al., 1980; and Allen, 1982).

Simply stated, DFA calculates a series of mathematical equations that maximize the distinctiveness of two or more groups of observations. The discriminant functions are linear combinations of a set of variables which describe each observation of each group. The groups must be determined a priori. For the CMCP study reaches this was accomplished using the ratings of the reaches derived during the selection process (table 4). Thus, the four study reaches which were not candidate transplant sites because C. caelata had been found at them during the previous five years were grouped together (Group 1). The remaining sites were arbitrarily divided into Groups 2, 3, and 4 in descending order of quality so that approximately equal numbers of study reaches were included in each group.

For the purposes of DFA, the hydrologic and water quality data were used as proposed discriminatory variables. This was done assuming that the physical and water quality characteristics of the study reaches have a substantial influence on the biotic communities. Also, the results of the similarity analyses of the biotic data suggested that

there was not a close relationship between the presence of C. caelata and a particular biotic community.

In order to identify important discriminating factors and to accommodate the large number of variables, a stepwise procedure was used (Nie et al., 1975). This procedure eliminated unimportant variables (those which added little discriminatory power to the function) in the process of forming each variate. An SPSS option was selected which acted to maximize the separation of the four group centroids.

The water quality data set presented a problem for DFA. At each site, 31 variables were measured monthly and, when expressed as seasonal means, became 4 x 31 = 124 potential variables. Dealing with all of these variables was circumvented by using the results of the principal component analysis (PCA) described in the Activity 6 (water quality) report. PCA was used as a data reduction technique which, in this case, reexpressed more than 60 percent of the total variation of the data set in terms of three abstract, statistically independent variables. The first three principal components for non-metals from the spring and summer seasons were used as the water quality discriminatory variables.

Metals were not considered because PCA generally indicated excessive random variation in these data. The historical review of water quality data (Activity 6) indicated that concentrations of dissolved metals were not likely to be a serious problem at any of the study reaches. The principal components for non-metals could be easily identified in terms of total ionic content, nutrient content, and residue for both seasons. No similar interpretations were apparent for the metal principal components.

Similarity Indices

Qualitative and quantitative similarity coefficients were calculated to compare data from the numerically best site for Conradilla caelata, Lillards Mill (DRM 179.1), with each of the other 14 study reaches. Qualitative biotic comparisons were made for six taxomic or ecological categories of the data. Within each category, Jaccard Coefficients were calculated by comparing presence/absence data (Lillards Mill to each of the other study reaches) for each animal or plant species encountered during the various surveys. The similarity values for each category, the totals for all six categories, and the relative ranking of these totals were used to compare the degree of similarity of the various study reaches to Lillards Mill.

These qualitative similarity index totals and ranks (table 5) indicate that Lillards Mill was most similar to the adjacent reaches on the Duck River (Sowell Ford, DRM 159.4, and Halls Mill, DRM 202.2) and least similar to Copper Creek (CCRM 1.9) and Topsy Bridge (BRM 79.9). The fish assemblages at Halls Mill and Sowell Ford were especially similar (high values) to Lillards Mill. Copper Creek showed especially low similarity with Lillards Mill for zooplankton while Saltville appeared to have a macroinvertebrate assemblage of species considerably different from those occurring at Lillards Mill. In general, large stream study reaches were relatively similar to Lillards Mill and small stream reaches were generally dissimilar. Kyles Ford (CRM 189.5), a large stream reach known to support a diverse mussel community--including Conradilla caelata--ranked third in similarity to Lillards Mill.

Calculations of qualitative similarity coefficients using Kyles Ford as the reference study reach (table 6), showed similar results. The three reaches most similar to Kyles Ford were nearby, large streams (Buchanan Ford, PRM 99.2; and Fletcher Ford, PRM 117.4 and Fort Blackmore, CRM 227.4), while the three most disimilar were distant, small streams (Dement Bridge, DRM 243.1; Elk River, ERM 91.4 and Topsy Bridge, BRM 79.9). Lillards Mill ranked sixth in this comparison. Buchanan Ford, Fort Blackmore, Fletcher Ford, and Click Island all showed relatively high similarities for fish and macroinvertebrates. Elk River and Lillards Mill showed particularly low similarities for macroinvertebrates. The Elk River zooplankton value also was quite low.

A number of the study reaches do not have large resident mussel communities. While this fact may be pertinent to determining whether these reaches could support transplanted mussel populations, it also may be related to the extremely long time for mussel populations to recover from pollution events (Crossman, Cairns, and Kaesler, 1973) or to the fact that impoundments and other barriers may have isolated these study reaches from natural sources of recolonization.

In an attempt to remove this possibly ambiguous information from the evaluation, the summary similarity coefficients were recalculated with the mussel contributions excluded (tables 5 and 6). These new ranks of the study reaches indicated that Halls Mill and Sowell Ford (both on the Duck River) were still most similar to Lillards Mill. Copper Creek and Saltville (NRHRM 85.2) were most dissimilar. Buchanan Ford, Fort Blackmore and Fletcher Ford were most similar to Kyles Ford. Elk River, Dement Bridge and Lillards Mill were most dissimilar.

These rankings were very similar to the rankings obtained from all six taxonomic categories. The notable exception was Lillards Mill which dropped from rank 6 in the six-category analysis to rank 12 in the five-category examination. Thus, while Lillards Mill and Kyles Ford had a considerable number of mussel species in common, these populations apparently exist in relatively dissimilar biotic communities.

Quantitative Biotic Similarities

The categories of quantitative biotic data used to compare the various study reaches to Lillards Mill and to Kyles Ford were the same as those used in the qualitative comparisons. In this case, the numbers of each species found at each reach contributed to the Euclidean distance values.

The Lillards Mill comparisons are presented in table 7. Once again the two adjacent Duck River study reaches (Sowell Ford and Halls Mill) were most similar (here the lowest numbers indicate the least dissimilarity) to Lillards Mill. The most dissimilar study reach was Hale Bridge (NRM 27.8) preceeded by the two Clinch River reaches (Fort Blackmore and Kyles Ford). Except for Dement Bridge, there seemed to be a clear zoogeographic relationship with most western study reaches being more similar to Lillards Mill than those reaches in the east. Kyles Ford (CRM 189.5) showed the most dissimilar mussel fauna compared to Lillards Mill, contrasting with the results of the qualitative analysis (table 5). This indicates that while many of the same species were present at these two study reaches, the species showed widely different patterns of dominance.

In the comparisons with Kyles Ford (table 8), the two Powell River study reaches (Buchanan Ford and Fletcher Ford) were most similar, followed by Click Island (NFHRM 6.2). The most dissimilar reaches were Lillards Mill, Hale Bridge (NRM 27.8), and Dement Bridge (DRM 243.1). Lillards Mill did have the most dissimilar mussel value, but the zoogeographic effect noticed in the Lillards Mill comparisons was not as apparent from the Kyles Ford perspective.

The rankings of study reaches excluding the mussel data (tables 7 and 8, bottom), showed relationships similar to those with the mussel data included. Sowell Ford and Halls Mill were most similar to Lillards Mill while Hale Bridge, Fort Blackmore and Saltville were most dissimilar. Buchanan Ford and Fletcher Ford were most similar to Kyles Ford while Hale Bridge and Lillards Mill were most dissimilar. This near agreement in rankings between the quantitative data with and without the mussel data set apparently reinforces the observation that the Jaccard Coefficient technique adds some bias to qualitative comparisons of sites with few taxa in common.

Quantitative Physical/Chemical Similarities

Calculations of Euclidean distances for the hydrologic and water quality data sets were identical to those performed for the quantitative biotic information. The categories of data included in this comparison included hydrologic data from Activity 5--variables describing the morphology and flow regime of each reach--and two categories of non-metals water quality variables for Activity 6--those for the spring and summer seasons. Two seasons of the water quality data set were chosen because the Activity 6 analysis indicated that

there were substantial differences between the data collected during the various seasons. These specific seasons were chosen for comparative purposes because freshwater mussels typically spawn and grow during the summer season, and glochidia are typically released and complete their parasitic existence during the spring season.

The resulting comparison of study reaches with Lillards Mill (table 9), indicated that the two adjacent Duck River study reaches (Halls Mill and Sowell Ford) again were least dissimilar. The most dissimilar reaches were Saltville (NRHRM 85.2) and Hale Bridge (NRM 27.8). The study reaches on the Clinch and Powell Rivers (including Kyles Ford) were all relatively similar to Lillards Mill while several geographically closer sites (including Dement Bridge, DRM 243.1) were dissimilar.

Comparisons with Kyles Ford (table 10) gave the same results. The most similar study reaches were the adjacent ones on the Clinch and Powell Rivers (Buchanan Ford, PRM 99.2; Fort Blackmore, CRM 227.4; and Fletcher Ford, PRM 117.4) and the most dissimilar reaches were relatively distant (Estill Fork, PRRM 60.0; Dement Bridge, DRM 243.1, and Topsy Bridge, BRN 79.9).

In general, all of the similarity evaluations that were performed indicated that Halls Mill (DRM 202.2) and Sowell Ford (DRM 159.4) were consistently quite similar to Lillards Mill. Likewise, Buchanan Ford (PRM 99.2) and Fletcher Ford (PRM 117.4) consistently ranked as being quite similar to Kyles Ford. Following these close associations, Elk River (ERM 91.4), twice ranked third in similarity to Lillards Mill; and Fort Blackmore (CRM 227.4), twice ranked as one of the three reaches most similar to Kyles Ford.

At the other end of the spectrum, Hale Bridge (NRM 27.8) and Saltville (MFHRM 85.2) were each twice members of the three sites most dissimilar to Lillards Mill. With respect to Kyles Ford, Dement Bridge (DRM 243.1) was consistently one of the three most dissimilar sites and Topsy Bridge (BRM 79.9) was in the most dissimilar group twice.

Perhaps the most interesting observation about all of these rankings is the lack of agreement between the two points of focus, Lillards Mill and Kyles Ford. None of the top three study reaches in any similarity ranking is shared by Lillards Mill and Kyles Ford. Since Conradilla caelata and numerous other mussel species occur at many of these areas, the similarity index data suggest that mussels must be able to live within a fairly broad range of environmental conditions.

Another interesting observation is that there is very little consistency among the most dissimilar sites. Out of the nine possible positions for the three least similar study reaches, seven were represented in the comparisons to Lillards Mill and six in comparisons to Kyles Ford. Three study reaches occurred on both lists: Dement Bridge (DRM 243.1) was listed three times on the Kyles Ford most dissimilar list and once on the Lillards Mill list; Hale Bridge (NRM 27.8) was on the Lillards Mill list twice and on the Kyles Ford list once; and Topsy Bridge (BRM 79.9) was on the Lillards Mill list once and on the Kyles Ford list twice.

Statistical checks indicated that the various similarity rankings should not be combined. Spearmans rank correlation coefficients indicated that the qualitative and quantitative biotic rankings (total including mussels) were not similar for either the Lillards Mill (Spearmans rank coefficient (r_s) = 0.352) or the Kyles Ford examinations (r_s = 0.339).

Discriminant Function Analysis (DFA)

In the first DFA run, nine hydrologic variables were examined. The stepwise procedure retained four variables as contributors to the final discriminant functions (table 11). Three reaches were misclassified: Elk River (Group 2) was most similar to the Group 4 reaches; Buchanan Ford (Group 1) was most similar to the Group 3 reaches; and Copper Creek (Group 3) was most similar to the Group 4 reaches. The first two discriminant functions accounted for 81 percent of the variation between groups and showed roughly equal contributions by both functions. The first discriminant function appeared to represent an inverse relationship between seven-year low flow and average flow, while the second function seemed to be an inverse relationship between seven-year low flow and average sediment load.

A scatter plot of the study reaches using the discriminant scores for the first two functions showed relatively little clear separation of reaches (figure 1). Group 1 study reaches generally scored lower on the first function indicating that these reaches had somewhat higher average flows and lower seven-year low flows when contrasted with other reaches. Generally the hydrologic variables alone did not appear to yield a separation of the study reach groups.

Water quality variables (abstract variables from PCA) were next analyzed by DFA (table 12). The stepwise analysis selected three to six variables for inclusion in the final discriminant functions. The disciminants were complex linear functions of these three variables and clear ecological interpretations were not readily apparent. The first discriminant function seemed to represent a contrast between spring

nitrogen nutrients and spring residue; the second function was primarily a reexpression of spring residue, and the third included a large contribution from the total summer dissolved ions.

Based on discriminant function scores, only 65 percent of the study reaches were correctly classified. Group 1 reaches were especially poorly classified; Kyles Ford and Buchanan Ford were most similar to Group 3 reaches while Sowell Ford was placed with Group 2 reaches. Halls Mill (Group 4) was closest to Group 2 sites and Hale Bridge (Group 3) was placed with Group 1.

When the study reaches were plotted using the first two discriminant functions (98 percent of the variation), there was little clear separation of the groups (figure 2). The Group 4 study reaches tended to stand out because they had higher scores for the first discriminant function.

Neither the hydrologic information nor the water quality data independently provided a strong separation of the groups of study reaches. The final DFA considered both data sets simultaneously and examined their joint discriminatory properties.

The stepwise analysis selected 8 of the 15 available variables for inclusion in the final 3 discriminate functions (table 13). Four variables from each data set were selected; average depth, average velocity, volume of the 20-year flood, and average sediment load from the hydrologic data; spring nitrogen nutrients (spring PCA component 1), spring total dissolved ions (spring PCA component 2), spring residue (spring PCA component 3), and summer nitrogen nutrients (summer PCA component 2) from the water quality data.

The discriminant functions were complex and difficult to interpret. The first function (which accounted for most of the separation between groups) appeared to represent a contrast between low average velocity and high spring total dissolved ions, while the second appeared to be an inverse relationship between average sediment load and spring residue.

All study reaches were classified correctly. When plotted, the study reach groups were clearly separated by the discriminant scores for the first two functions (figure 3). The first discriminant served to separate Group 4, Group 2, and Group 1/Group 3. The second function separated Group 1 from Group 3.

The results of this DFA lends support to the a priori notion that the study reaches can be considered as four or, possibly, three groups. The relatively distant locations of Groups 1 and 4 support the original ranking of these study reaches as the extremes being examined. However, this apparent pattern is confused by the close association of the Group 3 study reaches with Group 1 and the positioning of the Group 2 reaches near Group 4.

An additional DFA was performed in an attempt to determine whether the contrasts between study reach groups based on the physical/chemical parameters were similar to the contrasts between these groups based on biotic categories. The eleven summary biotic variables that were examined included five categories indicating abundance (by taxonomic group), five categories indicating species number (by taxonomic group) and the Activity 7 derived value for mean volatile solids.

A univariate analysis of these summary biotic variables was performed. (table 14). High positive within-group correlations were

observed for phytoplankton density with zooplankton density, phytoplankton species number with zooplankton species number, and phytoplankton species number with periphyton species number. The high correlations between the species number variables may indicate ranges in productivity among the groups of study reaches.

Generally, the means for these values were similar among the groups of study reaches (table 15). However, macroinvertebrate density and fish density were both highest in the Group 3 reaches and lowest in the Group 4 reaches. Univariate, one-way ANOVA indicated that both variables showed significant differences ($P<0.057$) among groups.

The stepwise DFA selected only five biological summary variables for inclusion in the discriminant functions (table 16). The first discriminant function (83 percent of the variance explained) appeared to represent a contrast between zooplankton density and phytoplankton density with a substantial contribution by the number of fish species. The second function (15 percent of vaiance) represented a combined effect by the number of fish species and the number of periphyton species.

Two study reaches were misclassified by DFA; Fletcher Ford (Group 3) was similar to Group 2 and Saltville (Group 2) was closer to Group 3. When plotted using the first two discriminant functions, Groups 1 and 4 were distinct but Groups 2 and 3 overlapped (figure 4). Group 1 plotted between the cluster for Groups 2/3 and Group 4.

Thus, while the DFA of the summary biological variables did sort some of the study reach groups, this analysis did not indicate any gradients among the classes that could be interpreted in terms of overall biological quality. The only exception was the indication that

Group 1 study reaches have slightly larger numbers of fish and periphyton species.

As the first step in trying to compile the various discriminant function analyses, the physical/chemical and the biotic DFA results were used to calculate two sets of Euclidean distances from each of the non-group 1 study reaches to the Group 1 centroid. For each DFA, the study reaches were then ranked based on these Euclidean distances (table 17). The study reach ranking based on the DFA using physical/chemical data bore essentially no concordance with the rankings from the DFA using biotic data (r_s=0.336). Therefore, there was no justification to calculate a true rank by adding the two rank values together (Ostle, 1963).

It was possible, however, to calculate mean Euclidean distances from each of the non-group 1 study reaches to the Group 1 centroid. Both sets of data had been standardized before the DFA were run which made the Euclidean distances produced by the two analyses compatable numbers. Mean Euclidean distances were calculated for each non-group 1 study reach by averaging the abiotic and biotic distances. These mean distances were then ranked (table 17).

Transplant Site Selection

The Criteria

The primary purpose of this analysis is to select sites to receive Conradilla caelata transplants from the Sowell Ford-Lillards Mill reach of the Duck River. These transplants are intended to start self-sustaining populations of C. caelata in the receiving streams. The

goal of these transplants, the endangered species status of C. caelata, and U.S. Fish and Wildlife Service (FWS) requirements concerning this program, all contribute to the list of criteria to be followed during this selection process. Each of the four identified criteria are discussed in following paragraphs; the remainder of this section describes the criterion-by-criterion selection of transplant sites.

Nothing in this selection process should be taken to imply that only the 15 specific 650-foot study reaches are available as transplant sites. The study areas should be considered to represent longer reaches of each stream. On this basis, more than one site could be selected for a given river reach.

Criterion 1--The process of selecting transplant sites for Conradilla caelata must include the results of comparisons of the study reaches using data collected for CMCP Activities 5-8. This obvious criterion emphasizes that the data and anlayses from CMCP Activities 5-9 are to form the basis for the transplant site selections.

Criterion 2--No natural population of C. caelata must occur at, or have access to, the transplant sites. Success criteria imposed by the FWS require recovery of juvenile mussels produced at the transplant sites by the transplanted adults; there is no way to distinguish between juveniles spawned by native animals and those spawned by transplants.

Criterion 3--The fish host for C. caelata (the banded darter, Etheostoma zonale) must be present at the transplant sites in numbers comparable to natural populations that have been sampled. This is an interim requirement of the FWS and a logical notion since successful reproduction is implicit in the success of the transplants.

Criterion 4--Sites on at least three streams must be selected (assuming that such sites are each biologically suitable). This also meets a FWS requirement.

Data Analysis Involvement

The various rankings of study reaches obtained from the similarity analyses and from the DFA were combined and a true ranking calculated only if Spearman's rank correlation coefficient indicated significant ($P< 0.05$) concordance (Ostle, 1963; Elliott, 1971).

To allow for comparisons between the similarity indices and the DFA (where only non-group 1 reaches were ranked) all Group 1 study reaches were deleted from consideration. When this criterion was applied to rankings from the similarity analyses, significant concordance was observed between the quantitative biotic rankings and the quantitative physical/chemical rankings for both Lillards Mill and Kyles Ford (r_s = 0.663 and 0.629, respectively). Therefore, true rankings representing the overall quantitative similarity could be calculated for each study reach. The rank order listing of the 11 non-Group 1 reaches for each of the two points of reference are:

Lillards Mill	Rank Order	Kyles Ford
Halls Mill	1	Fletcher Ford
Elk River	2	Click Island
Fletcher Ford	3	Elk River
Topsy Bridge	4	Fort Blackmore
Click Island	5	Halls Mill
Copper Creek	6	Copper Creek

Estill Fork	7	Saltville
Dement Bridge	8	Topsy Bridge
Fort Blackmore	9	Hale Bridge
Saltville	10	Estill Fork
Hale Bridge	11	Dement Bridge

These rankings did not show significant concordance ($r_s = 0.536$) and they were not combined.

Each of the above rankings was compared separately with the summary DFA ranking (table 17). The ranking for Lillards Mill showed no significant concordance with the DFA ranking ($r_s = 0.073$) while the Kyles Ford ranking showed significant concordance ($r_s = 0.755$). This allowed the computation of a true ranking combining the results from the Kyles Ford similarity analyses with the results from the DFA. The study reaches listed by rank are:

1. Fletcher Ford
2. Click Island
3. Elk River
4. Fort Blackmore
5. Copper Creek
6. Halls Mill
7. Saltville
8. Hale Bridge
9. Topsy Bridge
10. Dement Bridge
11. Estill Fork

The position of the last two reaches was determined by favoring of the DFA results. Both of these sites had identical total ranks and sums of squares of the ranks, constituting a complete tie.

Barring Conradilla caelata

During the 1979-1980 CMCP Activity 1 mussel surveys of various rivers and streams, live specimens of Conradilla caelata were found in the following areas: Clinch River, Miles 184.7-226.0; Duck River, Miles 132.0-179.1; and Powell River, Miles 94.8-120.7.

Live specimens of C. caelata were not found during the Elk River survey; however, empty shells of this species (in one case with some flesh still attached) were found at ERM 70.5 and 83.0. No live or recent shells of C. caelata were found during float surveys of the Buffalo River, Paint Rock River, upper Duck River (above RM 179.1), Nolichucky River, or Copper Creek. The study by Neves, et al. (1980) indicates that the North Fork Holston River can be added to the list of streams where C. caelata has not been found in recent years.

Based upon this survey information, seven designated study reaches are now known to be located on stream segments containing populations of C. caelata. The study reaches unacceptable as possible transplant sites are:

Clinch River

Kyles Ford, CRM 189.5 (Group 1)

Fort Blackmore, CRM 227.4 (Group 2)

Duck River

Sowell Ford, DRM 159.4 (Group 1)

Lillards Mill, DRM 189.5 (Group 1)

Elk River

Elk River, ERM 91.4 (Group 2)

Powell River

Buchanan Ford, PRM 99.2 (Group 1)

Fletcher Ford, PRM 117.4 (Group 3)

The Copper Creek study reach (CCRM 1.9) probably also should be added to this exclusion list because Copper Creek joins the Clinch River in the area populated by C. caelata (mouth at CRM 211.6).

Fish Host Presence

The fish host identification experiments conducted as a part of CMCP Activity 3 showed that the banded darter, Etheostoma zonale, was a fish host for Conradilla caelata. Examinations of fish communities conducted as part of CMCP Activities 2 and 8 provided comparable, quantitative data on the abundance of E. zonale at all of the study reaches and at 13 additional sites on the Duck, Powell, and Clinch Rivers. For the 19 studied sites located in river reaches where C. caelata occurs, the mean abundance rank for E. zonale was 16.74 and the standard deviation of this number is 8.48. These values can be used to suggest that 95 percent of all sites supporting C. caelata populations have E. zonale populations that rank 20th or better [16.74 + 1.734 (8.48/ 19) = 20.10] in abundance, where 1.734 is the critical value of Student's t distribution with a = .05 (one tailed test) and 18 degrees of freedom.

Applying this criterion to the list of possible transplant sites, several study reaches without resident C. caelata populations do have resident E. zonale populations that rank above the number 20 limit. The E. zonale ranks at these acceptable sites are Topsy Bridge BRM 79.9--6; Halls Mill, DRM 202.2--9; Click Island, NFHRM 6.2--13.5;

and Hale Bridge, NRM 27.8--15. The four study reaches that exceed the calculated limit are Estill Fork, PRRM 60.0--22; and Copper Creek, CCRM 1.9--24; Saltville, NRHR 85.2--25.5; and Dement Bridge, DRM 243.1, where no specimens of E. zonale were collected. Strict adherence to the calculated limit would preclude these four reaches from further consideration as possible transplant sites.

Three Rivers Represented

Table 18 summerizes the combined statistical ranking of the study reaches and the subsequent rankings after the two cycles of deletions had been made. Examination of the most restricted list of study reaches (after the fish host deletions) indicates that the remaining four sites are all located on different rivers. Any combination of transplant sites based on three or more of these study reaches would meet the final selection criterion.

Recommendations

The final list of four study reaches remaining for selection as transplant sites for Conradilla caelata includes a variety of stream sizes, geographic locations, and environmental conditions. These variations reflect the general dissimilarity between Lillards Mill and Kyles Ford. The highest ranking reach (Click Island, NFHRM 6.2) is similar in many ways to Kyles Ford while the second ranking study reach (Halls Mill, DRM 202.2) is quite similar to Lillards Mill (eventhough the Lillards Mill based similarity rankings were not included in the summary rankings). The close relationships of these high ranking sites to the best C. caelata study reach and the best overall mussel reach make recommending them as transplant sites an easy decision.

The other two study reaches on the list appear to require closer scrutiny before either of them is recommended as a transplant site. Both of these study reaches ranked low or last in some of the summary similarity indices. Topsy Bridge, BRN 79.9, was ninth in the quantitative physical/chemical similarity comparison with Kyles Ford and tenth in the qualitative similarity comparison with Lillards Mill. Hale Bridge, NRM 27.8, was last in the quantitative biotic similarity comparisons to both Lillards Mill and Kyles Ford.

With no information to indicate that one or the other of these study reaches is precluded from serving as a transplant site (no preclusive parameters were encountered in the DFA), neither site can be eliminated. If only one of these sites is to be selected to join Click Island and Halls Mill as recommended transplant sites, Hale Bridge would be the choice over Topsy Bridge, both because of the overall ranking and because of its relatively high ranking (2) in the abiotic DFA.

HABITAT CHARACTERIZATION

A second major objective of this report is to use the accumulated CMCP information to characterize the habitat of Cumberlandian mussel species. This exercise is intended to identify physical, chemical and/or biological factors that indicate good habitat for Cumberlandian species regardless of whether mussels live at a given site when it is studied. If a few factors correlate well with diverse Cumberlandian mussel populations, examination of these factors alone could be used to select transplant sites or to monitor habitats supporting sensitive species.

A second purpose of this exercise is to provide means and ranges of all factors measured at the CMCP designated study reaches, especially those reaches with good Cumberlandian faunas. While this information is not likely to establish critical levels of any environmental factor, the data will document conditions in which natural populations of these species exist in Tennessee River drainage streams. Comparisons of various factors at study reaches without, or with depauperate mussel faunas also may indicate possible causes and cures of existing environmental problems.

The approach used in the following analyses takes advantage of the fact that the fifteen designated study reaches support different numbers of freshwater mussel species. The first tasks of this section are to arrange the study reaches in order based upon the number of mussel species they support and to select those reaches which appear to be most appropriate for the eventual characterization of good Cumberlandian species habitat. These tasks are followed by separate statistical analyses for the physical, chemical and biological categories of measured factors to

identify apparent correlations with mussel species richness. A composite analysis follows, which identifies correlations between the factors that are related to mussel richness. The section concludes with a dicussion of the factors that characterize Cumberlandian and total mussel habitats.

Species Richness Order

The fifteen study reaches included in this program had been found (by activities 1 and 8) to support freshwater mussel communities including from 2 to 40 species. The study reaches were arranged by comparing the numbers of species found alive in each study reach (Activity 8) and in the adjacent 40-mile stream segment (examined for Activity 1). Data from the adjacent stream segments were incorporated to minimize the potential bias of comparing faunas of single shoals and to include records of rare species.

In table 19, one of the columns lists the number of mussel species encountered adjacent to each study reach along with the relative rank. An adjoining column in table 19 lists the number of Cumberlandian species (faunal designation per Ortmann, 1924) that were found in each stream segment, accompanied by the rank value of each reach based on this information.

Two other columns in table 19 present the weightings and rankings of study reaches derived from principal component analyses (PCA) of the total mussel and Cumberlandian species presence/absence data. The values presented for each study reach are the first principal component (PCI) weightings (accounting for 31 and 34 percent of the variation, respectively) from an analysis of the variance/covariance relationships based on the presence or absence of each mussel species in each stream

segment. This analysis technique emphasizes similarities of the mussel community among the stream segments--either total or Cumberlandian species only--instead of simply counting the number of species present. In both cases, the PCI factors appeared to weight for species richness. Zoogeographic and stream size factors became obvious in the second and third principal components in each analysis. These PCA analysis results were similar to cluster analyses results which did not allow for ranking the study reaches.

The final columns in table 19 present the numerical sum of the four sets of rankings and the overall rank of each study reach derived by this procedure. Study reaches with low overall rank numbers occur in stream segments supporting relatively similar, species-rich mussel communities, concentrating on Cumberlandian species. Study reaches with high overall rank numbers occur in stream segments with few Cumberlandian or other mussel species. Reaches with intermediate overall rankings support modest numbers of mussel species or they may have relatively unique mussel communities.

While this procedure arranged the study reaches by the makeup of their mussel communities, it did not clearly identify a specific number of good Cumberlandian reaches. The subjective decision to characterize Cumberlandian mussel habitat based upon the six study reaches indicated by asterisks (*) in table 19 was the outcome of applying two selection criteria. Study reaches which fell below the median overall rank number (8) were excluded, as were study reaches with negative weightings for the Cumberlandian species PCI. The first of these criteria selected the best half of the study reaches while the second concentrated the emphasis on the best habitats for Cumberlandian species.

Examination of Ecological Factors

Each of the following category by category evaluations of environmental factors uses correlation and partial correlation analysis techniques to search for factors that appear to be related to mussel species richness. It should be understood that these analyses may result in eroneous conclusions for at least two reasons. Correlation analysis looks for a linear relationship between two variables that were measured at different times or places (study reaches in this case). If many observations (study reaches) are included, statistical correlations of the data probably indicate true relationships. However, as the number of observations (study reaches) decreases, the reliability of apparent correlations also decreases. Six data points from the study reaches suggested to represent good Cumberlandian mussel habitat are too few to expect to generate reliable correlations; however, the full set of fifteen study reaches could be enough observations.

These analyses also could reach spurious conclusions because present-day mussel information was used to rank the study reaches. The (unsupported) assumption used in ranking the study reaches is that every Tennessee River drainage mussel species that could live in each stream segment was there when the area was surveyed. This assumption ignores the fact that distance and other physical barriers prevent equal access to some stream segments. It also ignores the very slow colonization rate that could be expected for these strictly aquatic animals with long generation times and complex life cycles.

Physical Factors

From the data collected and compared in CMCP Activity 5, eleven factors were selected to represent the physical components of the study reaches. These factors included direct descriptions of the reaches (drainage area, gradient, mean depth, mean width) and a variety of flow-related features (7Q10, average flow, daily average flow, velocity at average flow, average velocity, 20 year recurrence flood flow and suspended sediment at avearge flow). Some of these factors were derived directly from field or map information; others were produced by extrapolation from field and historical data. Units and summaries of the data for these factors at the study reaches are presented in appendix B.

Correlation analysis was used to search for apparent relationships between these factors and the first principal component factors for all freshwater mussel species (PC_ALL) and the Cumberlandian species (PC_CUM) derived in the ranking process. Numerical results of these comparisons are presented in table 20.

The correlation coefficients presented in table 20 indicate some statistically meaningful relationships between PC_ALL, PC_CUM and various physical factors. Three physical factors (drainage area, average width and average flow) have significant correlations (90 percent confidence level or better) with PC_ALL. No physical factor appears to be correlated with PC_CUM. Drainage area, average width and average flow also show significant correlations to five other factors (7Q10, average velocity, velocity at average flow, 20 year flood flow and suspended sediment). Most of these factors show significant correlations to each other.

Partial correlation analysis was used to examine whether the relatively strong drainage area/average flow relationship was masking

relationships of other physical factors to the mussel factors, especially PC_CUM. A preliminary analysis indicated that average flow accounted for nearly all of the relationship among other flow-related factors (7Q10, daily average flow, average velocity, velocity at average flow and 20 year flood flow). Partial correlations of the remaining factors controlled for average flow were quite similar to those controlled for drainage area.

The partial correlation coefficients of a few physical factors to the mussel factors controlled for the combined effects of drainage area and average flow are presented in table 21. The correlation between average width and PC_ALL was removed by the controlling factors. None of the other factors has significant correlation coefficients with either of the mussel factors. This leads to the conclusion that, of the physical factors examined, the very similar effects of drainage area, average width, and average flow appear to account for the sole correlation with mussel diversity. More importantly, perhaps, not even this relationship holds when only the Cumberlandian species are considered.

Chemical Factors

Thirty-one chemical factors, measured and examined as part of CMCP Activity 6, were used in this analysis. Summary data for each of these factors are presented in appendix C.

Table 22 presents correlation coefficients between these chemical factors and the mussel factors PC_ALL and PC_CUM. This table includes results based upon comparisons of the full eleven months of data along with comparisons using only the summer-fall (May and July through October) or the winter-spring (November through April) data. These subsets of the data were examined because the Activity 6 analysis indicated that significant

differences existed between data collected in various seasons of the year. The data were grouped into two semi-annual periods to approximate metabolically active and passive seasons for the mussels.

Statistically significant correlations in table 22 indicate relationships between the mussel factors and several chemical factors. In general, the Cumberlandian mussel factor (PC_CUM) appears to be related to more chemical factors than does the total mussel factor (PC_ALL). For five chemical factors (alkalinity, conductivity, hardness, total residue and sulfate) seasonal differences do not appear to affect the relationship to mussels; however, other factors only appear to show relationships during one of the semi-annual periods.

Specific relationships among the mussel and chemical factors were explored, in part, by looking at correlations within three broad groups: a hardness group, a metals group and an "others" group. This approach facilitated the examination of correlations among similar factors and assisted in selecting relationships to be tested using partial correlation analysis.

Hardness Group--The hardness group consisted of nine ionic factors or standard measures of elements typically dissolved in fresh water. Correlation coefficients among these and the mussel factors (table 23) indicate a large number of apparent relationships. Seven of the nine factors appear to be correlated with the Cumberlandian mussel factor (PC_CUM) and three of them appear to be correlated with the total mussel factor (PC_ALL). Conductivity, total residue, and hardness are closely correlated with each other. These factors correlate with alkalinity; with sodium, chloride and

calcium as a group; and with sulfate. Dissolved residue appears to correlate only with sulfate and the mussel factors.

A few of these relationships were explored further using partial correlation analysis. In one case, the effect of alkalinity was held constant and revised correlation coefficients were calculated for the relationships between the mussel factors and most of the other hardness group factors (table 24). The reduced correlation values between PC_CUM and calcium, conductivity and total residue indicate that these factors (also probably including hardness) share a common correlation with alkalinity. The inflated correlation coefficients between dissolved residue or sulfate and the mussel factors indicate that these relationships are not closely tied to alkalinity.

In a second partial correlation analysis, the data were corrected for the effect of sulfate and revised correlation coefficients were calculated. These results (table 25) indicate that sulfate accounts for virtually all of the relationship between one or both mussel factors and conductivity, total residue and dissolved residue. Sulfate does not affect the relationship between PC_CUM and alkalinity.

Taken together, these correlation and partial correlation results suggest that the total mussel factor is correlated to hardness, dissolved residue and sulfate but that sulfate alone accounts for a significant portion of these and other similar relationships. With regard to the Cumberlandian mussel factor, sulfate accounts for much of the significant relationships to conductivity, total residue and dissolved residue. Alkalinity also interacts in the relationships between PC_CUM and conductivity or total residue, as well as accounting for the apparent relationship to calcium. In general, sulfate concentration (and its

correlates) appears to be higher where both the total and Cumberlandian mussel faunas are more species rich. Alkalinity (and its correlates) appears to be higher where more Cumberlandian mussel species occur, but this relationship does not hold when the total mussel faunas are considered.

Metals Group--Full year correlations among the mussel factors and thirteen metal factors are presented in table 26. Both mussel factors show similar degrees of relationship to most of these factors and both appear to correlate with aluminum, total iron and selenium. Aluminum and iron correlate with each other but neither shows an apparent relationship to selenium.

Table 26 also presents correlation coefficients between these metal factors and the mussel factors for the summer-fall and winter-spring semiannual periods. The aluminum and total iron relationships indicated in the full year presentation, in actuality, only occur in the winter-spring data. The selenium relationship appears to be a summer-fall phenomenon. Chromium shows positive correlations to both mussel factors in winter-spring and non-significant negative correlations in summer-fall. Copper shows significant positive correlations to both mussel factors in summer-fall and a significant negative correlation to PC_ALL in winter-spring. Dissolved iron gives a negative relationship to PC_ALL only in summer-fall.

This seasonal examination of the metals data suggests that six factors--not two--correlate with the mussel factors. Possible relation-

ships among these factors (aluminum, chromium, copper, dissolved iron, total iron and selenium) were explored using partial correlation analysis. Data from both semiannual periods were corrected for the effect of total iron (which is very closely correlated to aluminum) and revised correlation coefficients were calculated (table 27). Summer-fall correlations were virtually unaffected by total iron but, in the winter-spring relationships, chromium, dissolved iron and selenium were all affected. In particular, the chronium correlation to PC_ALL was removed by the total iron correction.

These analysis results suggest that total and Cumberlandian mussel species richness are both (positively) correlated with winter-spring aluminum/total iron levels. The total mussel factor also is correlated with dissolved iron levels (negatively) and with selenium levels (positively) during the summer-fall period. Copper appears to be positively correlated with both mussel factors during the summer-fall months and negatively correlated with PC_ALL during the winter-spring months.

Others Group--The nine chemical factors which were not considered in the hardness group or in the metals group included nitrogen-related factors (ammonia, organic nitrogen and NO_2-NO_3), oxygen-related factors (biological oxygen demand, chemical oxygen demand, and dissolved oxygen), pH, temperature and total organic carbon. Correlation coefficients among these factors and to the mussel factors are presented in table 28. None of these chemical factors appears to be related to the mussel factors when all of

the data are considered together; however, dissolved oxygen correlates with PC_CUM in the summer-fall subset and chemical oxygen demand correlates with both mussel factors in the winter-spring subset. Biological oxygen demand, organic nitorgen and total organic carbon correlate with each other. Chemical oxygen demand correlates with organic nitrogen and total organic carbon but not (significantly) with biological oxygen demand.

In partial correlation analysis of these data, when the organic nitrogen effect was held constant, the results (table 29) generally indicate that organic nitrogen is not masking other relationships between the mussel factors and these chemical factors. Both the positive correlation of chemical oxygen demand to each of the mussel factors during the winter-spring period and the summer-fall positive correlation of dissolved oxygen to PC_CUM appear to be significant, independent factors.

Chemical Summary--In preceeding separate analyses of the three groups of chemical factors, nine factors were found to correlate with one or both of the mussel factors during part or all of the year. Correlates with the total mussel factor (PC_ALL) were: sulfate (all year); dissolved iron, selenium and copper (summer-fall only); and aluminum/total iron, copper and chemical oxygen demand (winter-spring only). Correlates with the Cumberlandian mussel factor were: alkalinity and sulfate (all year); copper and dissolved oxygen (summer-fall only); and aluminum/iron and chemical oxygen demand (winter-spring only). Relationships among these important factors in the different chemical groups are examined as part of the composite analysis (see below).

Biological Factors

Data collected and analyzed as parts of CMCP Activities 6, 7, and 8 were used to construct fifteen biological factors for this analysis. With the exception of the bacteriological data, each identified category of organisms supplied information for a quantitative factor (numbers per area or volume) and a qualitative factor (numbers of taxa present) used in the analysis. Units and study reach means and extremes for these factors are presented in appendix D.

Correlation coefficients among these factors and to the mussel factors are presented in table 30. Four factors (total coliform, fecal streptococcus, periphyton taxa and fish density) showed apparent correlations to one or both of the mussel factors. Among the biological factors, zooplankton taxa showed significant correlations to the largest number of other factors (6), followed by zooplankton density, bottom fauna density and botton fauna taxa (4 each). The quantitative and qualitative factors were correlated within the macrophyte, phytoplankton, zooplankton and bottom fauna ecological groups; however, the periphyton and fish groups showed no such correlations.

The bacteriological data, unlike most of the other biological information, had been collected throughout much of a full year (11 months). Semiannual analysis of the bacteriological factors indicated that all were (negatively) correlated with one or both of the mussel factors during the summer-fall season and that they showed no correlations to the mussel factors during the winter-spring season. Partial correlation analysis of the bacteriological data indicated that total coliforms accounted for a significant portion of the fecal coliform effect but that fecal streptococcus was a separate factor.

Partial correlation analysis controlled for the effect of zooplankton (table 31) resulted in no indications of masking. Correlation coefficients were altered rather little, with total coliforms, periphyton taxa and fish density retaining most of their significant values.

These analysis results suggest that four distinct biological factors correlate with one or both of the mussel factors. Total coliforms and fecal streptococcus show negative correlations to both mussel factors during the summer-fall period. Periphyton taxa is positively correlated with PC_CUM and fish density is positively correlated with PC_ALL.

Composite Analysis

The preceeding examinations of physical, chemical and biological factors have identified a number of apparent correlations to one or both of the mussel factors. Close correlates were identified which, effectively, reduced the number of indicated relationships between the mussel factors and measured ecological components. Additional relationships among these mussel-related factors were sought by conducting a series of analyses in which all of the important factors were included.

Table 32 presents a summary of all the factors which had significant (90 percent confidence level or better) correlations to either the total (PC_ALL) or Cumberlandian (PC_CUM) mussel factors. In the table, close correlates identified in the preceeding paragraphs have been grouped with the factor which had the strongest or most distinct correlation to the mussel factor. Partial correlation analyses of these seasonal data are presented in tables 35 and 36. Both the summer-fall and winter-spring tables present partial correlation coefficients controlled for the effect of three separate factors: drainage area, alkalinity and sulfate.

These composite correlation and partial correlation results (tables 33 through 36) indicate several relationships among factors. In one case, the correlation data indicate that sulfate levels are related positively to both mussel factors and fish density (all year), and to aluminum and chemical oxygen demand (at least in winter). Sulfate is negatively correlated to total coliform and fecal streptoccus levels (at least in summer). Controlling for the effect of sulfate in partial correlation analysis accounts for a major portion of each of the statistically significant relationships between the mussel factors and these factors except for the total coliform-PC_ALL interaction. The partial correlation results and high correlations with both mussel factors suggest that sulfate concentration can be used to represent several of these factors as an indicator of mussel habitat quality. While summer-fall total coliform levels may be independently related (negatively) to the presence of a rich total mussel community, sulfate concentration is closely correlated to both total and Cumberlandian mussel species richness--more so than its correlates fish density, aluminum, chemical oxygen demand, or fecal coliform levels.

The summer-fall correlation analysis indicates significant relationships between alkalinity and copper, dissolved iron, dissolved oxygen, and periphyton taxa; however, copper and dissolved iron do not have significant correlations to dissolved oxygen, periphyton taxa or each other. Alkalinity, dissolved oxygen, and periphyton taxa are significantly correlated with each other and with PC_CUM but not with PC_ALL. Results of the partial correlation analysis (table 35) indicate that alkalinity accounts for much of the relationships between PC_CUM and dissolved oxygen

or periphyton taxa. Given its stronger correlation to PC_CUM, alkalinity appears to be the best of these indicators of Cumberlandian mussel quality. It also accounts for much of the negative relationships between dissolved iron and both mussel factors.

Drainage area, copper and total coliforms are closely correlated with each other and with one or both of the mussel factors (tables 33 and 34). Controlling the data for the effect of drainage area did not substantially reduce correlations with the mussel factors for either copper (tables 35 and 36) or total coliforms (table 35). Positive copper correlations to the mussel factors were not affected greatly by controlling for alkalinity or sulfate in the summer-fall data set; however, the negative correlations for copper with the mussel factors in the winter-spring data set were strengthened by both controlling factors. Regardless of their strong correlations with each other, drainage area, copper and total coliforms should be considered separately as they relate to mussel habitat quality. Drainage area is positively correlated with total mussel species richness. Both total and Cumberlandian mussel species richness are correlated with summer-fall copper (positively) and total coliform (negatively). Total mussel species richness is negatively correlated with winter-spring copper levels.

Selenium is the remaining factor included in this composite analysis. It was not involved with any factor except PC_ALL in a statistically significant correlation (table 33) but had highest correlation values with drainage area (0.43, p=0.13) and total coliforms (-0.39, p=0.15). The correlation to PC_ALL was most affected (reduced to a nonsignificant level) by the partial correlation correction

for drainage area (table 35). Without further evaluation, selenium probably should be treated as an independent factor in matters pertaining to total mussel habitat quality.

Potential Bias

Prior to using the results of these analyses to characterize good mussel habitat, it is important to mention, and briefly explore, the limits and biases that exist in this data set. The purpose of this digression is not to detract either from the data or the characterization, but to call attention to data attributes which have affected the analyses and which, otherwise, are indicated only in the appendices.

Appendices B, C, and D list summaries, units, and the number of observations which contributed to each factor mean used in these analyses. For each study reach, some factors are represented by single values (i.e., drainage area, macrophyte taxa) while others are represented by several readings (i.e., alkalinity, benthic density). In several instances, the number of observations contributing to each study reach or seasonal mean varied considerably and is quite likely to have affected the analysis results. As an example, bacteriological samples were collected monthly at all study reaches and were sent to a central laboratory for counting. Delays in receiving and counting samples from some sites resulted in variable sample sizes and some voids. Such occurrences were unavoidable in the accumulation of this large and complex data set. No attempt has been made to correct or exclude any affected factors.

A significant bias in the entire analysis program is the use of extant mussel communities to rank the study reaches, orient the factor

analyses (using the PCAs) and characterize habitats. Since the purpose of this analysis was habitat characterization, some mussel-related orientation was required. The use of a single "perfect" reference site was eliminated because important groups of Cumberlandian species occur in demonstrably different habitats (see transplant site selection discussion). Extant species richness in the adjacent river reach was chosen in the absence of any other acceptable option. As briefly mentioned earlier, the assumption made in using information concerning the extant fauna is that present distribution patterns match habitat capability. The analysis becomes biased when species are not present in suitable habitat or when they persist in marginal or unacceptable habitat. No test for this possible bias was available until controlling or important factors had been identified. Now that some correlations between the mussel factors and ecological variables have emerged, it may be possible to determine if substantial bias was included.

Two Powell River sites (Fletcher Ford and Buchanan Ford) were selected as study reaches because they support large, diverse mussel communities. They rank among the best Cumberlandian study reaches involved in the analysis. These study reaches were included in spite of substantial impacts to the river from extensive coal mining (and other) activities in the watershed. The effect these reaches have had in the analysis can be approached by comparing results including and excluding their data.

Table 37 presents PC_ALL and PC_CUM correlation coefficients for key water quality factors with and without the contribution of the Powell River study reaches. Of these factors, relationships involving alkalinity, dissolved oxygen and sulfate are not affected greatly by excluding the Powell River study reaches. However, for each of the other five factors,

excluding the Powell River reaches, results in substantial changes to the relationships with the mussel factors. With these study reaches excluded, aluminum, chemical oxygen demand and dissolvd iron no longer have significant (90 percent confidence level) correlations to either mussel factor. At the other extreme, the positive summer-fall relationship between copper and both mussel factors is replaced by a strong but not significant (p=0.12) negative relationship to PC_ALL. A similar reversal occurs in the winterspring copper relationships and in both the winter-spring and summer-fall selenium relationships.

If the Powell River study reaches are degraded mussel habitats, this brief test indicates their inclusion has affected some correlations. Similar exclusion tests with study reaches supporting few mussel species might result in equally divergent correlations. Since this is virtually a pioneering effort with regard to defining Cumberlandian mussel habitat, it may be most appropriate to complete the characterization supported by the data and to acknowledge that biases may have been incorporated. Future studies will demonstrate the number and types of biases incorporated in this study.

Characterization

The purpose of this analysis program has been to identify ecological factors which indicate good Cumberlandian mussel habitat. In category-by-category analyses, several factors were found to correlate with the Cumberlandian and/or the total mussel principal component factor. The composite analysis completed the grouping of these factors into sets of correlates that followed similar relationships to mussel species richness.

This summary section uses the analysis results to relate Cumberlandian and total mussel species richness to the identified trends. Some trends apply to both the total and Cumberlandian components; they are described first, followed by trends unique to each mussel factor.

Both Mussel Factors

Table 32 lists 24 ecological factors (three of which are listed twice) that correlate to one or both of the mussel factors. Examination of the statistically significant relationships indicates that nine factors correlate with both PC_ALL and PC_CUM. These factors include sulfate and its close correlates dissolved residue and hardness, aluminum and its close correlates total iron and chromium, (all winter-spring season), copper, and total coliforms (summer-fall season), and chemical oxygen demand (winter-spring season). In the composite analysis, all of these factors expect copper and total coliforms were found to correlate closely with sulfate.

Sulfate and most of these other chemical factors are positively correlated with the mussel factors. Summary data presented in appendix C indicate that the six good Cumberlandian study reaches had an overall mean sulfate value of 29.85 mg/1 with extremes ranging between 4.0 and 80.0 mg/1. The lowest good Cumberlandian study reach mean (for Coppr Creek) was 7.39 mg/1. The nine other study reaches had mean sulfate values that ranged between 3.05 and 25.17 mg/1 with an overall mean of 9.74 mg/1. Similar comparisons for the other factors can be obtained from the appendices.

These positive relationships between both mussel factors and

chemical factors such as sulfate, copper, aluminum, and chromium are contrary to expectations. Conventional wisdom would predict negative mussel correlations with most metal ions in streams, primarily because high metal concentrations often result from major land disturbances in a watershed. While the apparent correlations could be spurious results of misclassifying degraded mussel habitats, these relationships also could be valid indications of mussel habitat enhancement with increased electrolite levels or buffering capacity.

Summer-fall coliform count was the single factor negatively correlated with both PC_ALL and PC_CUM. Full data set mean values for the good Cumberlandian study reaches (appendix D) ranged between 75,000 and 400,000 colonies per 100 ml, with a composite mean of 235,000 colonies while the other study reach means ranged between 82,000 and 1,300,000 with a composite mean of 287,000 colonies per 100 ml. Extreme values of both types of study reaches ranged from <10 or 20 to 3 or >4 million colonies. No useable total coliform counts were made for the Buffalo River study reach (Topsy Bridge). The negative correlation suggests that where high total coliform levels occur, few mussel species are found. While this correlation could imply a plausable cause and effect relationship, the incomplete and extremely variable data set could easily have yielded a spurious result.

Cumberlandian Species

Table 32 indicates the Cumberlandian species richness factor (PC_CUM) was correlated with seven environmental variables in addition to sulfate (and its correlates), copper and total coliforms. These factors included alkalinity and its close correlates calcium, conductivity, and

total residue; dissolved oxygen (summer-fall); periphyton taxa; and fecal coliforms (summer-fall). In the composite analysis, both dissolved oxygen and periphyton taxa were found to correlate with alkalinity. Fecal streptococcus (a close correlate of fecal coliforms) correlated with sulfate.

Mean alkalinity levels at good Cumberlandian study reaches ranged from 79.9 to 173.3 mg/l with an overall mean of 109.5 mg/l. At the other study reaches, the means ranged from 41.9 to 130.5 mg/l with an overall mean of 79.1 mg/l. Only one minimum value at the six Cumberlandian reaches was below 50 mg/l (14.0 mg/l at Kyles Ford) but four of the nine other reaches had minimum values below 50 mg/l (27.0 mg/l at Dement Bridge, 48.0 mg/l at Halls Mill, 29.0 mg/l at Hale Bridge and 30.0 mg/l at Topsy Bridge).

Alkalinity and its hardness group correlates fulfill an expected relationship with mussel species richness. Calcium carbonate is the major component of mussel shells and the limestone bedrock streams of Kentucky, Tennessee, and northern Alabama are widely known for the abundance and diversity of their mussel faunas. Given this expectation, it is quite curious that the total mussel factor (PC_ALL) did not share significant correlations to alkalinity, calcium, or conductivity.

While all of the alkalinity-related factors were postively correlated to PC_CUM, the data on summer-fall fecal coliform levels produced a negative correlation. Like the total coliform data, study reach information on fecal coliform levels varied tremendously with regard to both the number of observations and colony counts. Overall mean values for the Cumberlandian and other study reaches differed by less than one percent (12,098 colonies per 100 ml for the Cumberlandian reaches to 12,191

colonies per 100 ml for the other sites) while the range of counts at both groups of study reaches varied from less than one thousand to one million and more per 100 ml. This statistical correlation exists in this data set; however, it should be confirmed in a specifically targeted experiment before being applied in mussel habitat characterization or selection exercises.

Total Mussel Species

Eight factors listed in table 32 were involved in significant correlations only with PC_ALL. These factors were drainage area and its close correlates average flow and average width, fish density, copper (winter-spring season) and--during the summer-fall season--dissolved iron, selenium and fecal streptococcus.

Drainage area did not yield a significant correlation with any environmental factor in the winter-spring composite analysis (table 34). In the summer-fall composite analysis (table 33), drainage area was correlated with copper and total coliforms; however, both of these factors retained significant relationships to the mussel factors in the partial correlation analysis controlled for the effect of drainage area (table 35).

The positive correlation between total mussel species richness and drainage area, average flow or average width indicates that more mussel species should occur as watershed and stream size increase. This relationship is an acknowledged fact among freshwater malacologists and has been attributed to larger numbers of available niches and/or more diverse fish faunas. The correlation with fish taxa was not indicated in this data set but the positive correlation between fish diversity and PC_ALL may be relevant.

Several mussel distribution surveys in the Tennessee River watershed (including the CMCP survey--see Activity 1 report) indicate that the Cumberlandian fauna also follows the "bigger stream-more species" rule. This relationship is clearly not indicated in this data set.

The seasonal correlations between PC_ALL and copper, dissolved iron, selenium, and fecal streptococcus levels are difficult to evaluate. Winter-spring copper levels were negatively correlated with PC_ALL, opposite from the copper relationships to both mussel factors in the summer-fall analysis. Dissolved iron correlated wih alkalinity in the composite analysis and was most affected by controlling for alkalinity in the partial correlation analysis, yet it correlated with PC_ALL while alkalinity and the other close correlates were all involved in significant relationships to PC_CUM. The overall selenium means for the Cumberlandian and other study reaches differed by 0.18 µg/l (appendix C) and, with the exception of single readings of 13.0 (at Kyles Ford) and 4.0 µg/l (at Click Island), were all either 1 or 2 µg/l. Fecal streptococcus counts ranged from less than 1,000 to over 200,000 per 100 ml and some study reaches were represented by five or fewer monthly means (appendix D). The available data for each of these factors led to significant correlations with PC_ALL; however, with the possible exception of fecal streptococcus (a general detrimental effect of high bacterial levels), none of these correlations corresponds to expected or obvious relationships to mussel habitat. Additional data or more specific experiments may well document that some or all of these apparent relationships are spurious.

Comments concerning each of the key factors discussed in this section are summarized in table 38. Considered together, these key factors distill a tremendous amount of physical, chemical, and biological

information down to nine (or fewer) relationships concerning the quality of freshwater mussel habitats. Future use of these relationships and the results of specific experiments designed to test their validity will demonstrate how completely they succeed in this characterization.

Table 1. Prospective stream reaches to be evaluated for selection as designated study reaches for the Cumberlandian Mollusk Conservation Program.

Stream Reach	Location by River Mile	Drainage area in sq. mi.	7 day/10 year flow in cfs
Duck River Drainage			
Duck River above Leftwich	160-164	1000	36
Duck River below Lillard Mill Dam	179	916	40
Duck River below Shelbyville	190-215	500	42
Duck River above Shelbyville	227-248	233	27
Buffalo River above Lobelville	26	500	150
Elk River Drainage			
Elk River at Dickey Island	113	671	153
Sugar Creek	2	174	23
Flint River above FM 20	20	375	78
Paint Rock River above FM 12	12	414	6
Short Creek above Guntersville Res.	9	92	1
Battle Creek	10	117	3
Little Chickamauga Creek	1	48	17
South Chickamauga Creek	31	115	17
Clinch River Drainage			
Obed River	1	520	1
Clear Creek (Emory River Dr.)	1	173	1
Powell River at Buchanan Ford	99	580	64
Powell River at McDowell Shoal	106	600	61
Copper Creek near Spring Mill Dam	2	131	21
Clinch River at Brooks Island	183	1000	115
Clinch River at Kyles Ford	189	1000	110
Clinch River at Pendleton Island	226	900	70
Little River above Pistol Creek	8	302	54
Holston River Drainage			
North Fork Holston River at Click Island	6	672	56
North Fork Holston River above Saltville	85	223	22
Middle Fork Holston River (upper reach)	28	155	30
Roan Creek (Watauga Dr.)	6	100	7
Doe River (Watauga Dr.)	1	137	17
French Broad River Drainage			
Nolichucky River at Solomon Island	3	1756	64
Nolichucky River at Johnson Island	14	1679	60
North Toe River	50	50	11

Table 2. Criteria for the evaluation of potential Cumberlandian Mollusk Conservation Program designated study reaches and the relative weights assigned to each.

Criteria	Weight
Absence of a suitable substrate for mollusks	10
Absence of a diverse fish fauna	10
Near recent or pending channelization	10
Downstream from a substancial municipal or industrial outfall	9
Absence of a diverse freshwater mussel fauna	8
No extant populations of *Conradilla caelata* or *Quadrula intermedia*	8
Seven day/ten year minimum flow less than 25 cfs	6
Potential for impact on anticipated mineral resource utilization	6
Potential impact by landfill site	5
Near a substantial municipal or industrial water supply	5
Within 20 miles downstream of a major impoundment	4
Potential land use impact	4
Potential impact from a major transportation route	4

Table 3. Matrix evaluation of potential Cumberlandian Mollusk Conservation Program designated study reaches.

Stream Reach	Criteria														
	No suitable substrate for mollusks	No diverse fish fauna	Recent of pending channelization	Municipal or industrial outfall	No diverse freshwater mussel fauna	C. caelata or S. intermedia absent	7 day/10 yr flow below 25 cfs	Potential impact on resource utilization	Potential impact from landfill site	Municipal or industrial water supply	Impoundment less than 20 mi. upstream	Potential land use impact	Potential transportation route use impact	Total Score	Reach Ranking
Duck River Drainage															
Duck River - Leftwich	-	-	-	-	-	-	-	-	-	-	4	-	-	4	1
Duck River - Lillard Mill	-	-	-	9	-	-	-	-	-	-	-	-	-	9	3
Duck River below Shelbyville	-	-	-	9	8	8	-	-	-	-	-	4	-	29	18
Duck River above Shelbyville	-	-	-	-	8	8	-	-	-	-	-	-	-	20	13
Buffalo River - Lobelville	10	-	-	9	8	8	-	-	-	5	-	-	-	40	24
Elk River Drainage															
Elk River at Dickey Island	-	-	-	-	-	8	-	-	-	-	-	-	4	12	6
Sugar Creek	-	10	-	-	8	8	6	-	-	-	-	-	-	32	20
Flint River above RM 20	10	-	-	-	8	8	-	-	5	-	-	-	-	31	19
Paint Rock River above RM 12	-	-	10	-	-	8	6	-	-	-	-	-	-	24	16
Short Creek above Guntersville	10	10	-	9	8	8	6	-	-	-	-	-	4	55	29
Battle Creek	10	10	-	-	8	8	6	-	-	-	-	-	-	46	26
Little Chickamauga Creek	10	10	-	-	8	8	6	-	-	-	-	-	-	42	25
South Chickamauga Creek	10	10	-	-	8	8	-	-	-	-	-	-	-	36	23

(table continues)

BEST COPY AVAILABLE

Table 3. (continued)

	substrate	fish	channelization	outfalls	freshwater mussels	C. caelata or Q. intermedia	minimum flow	resource utilization	landfill impact	water supply	upstream impoundment	land use	transportation route impact	Total Score	Reach Ranking
Clinch River Drainage															
Obed River	10	-	-	9	8	8	6	6	-	-	-	-	4	51	28
Clear Creek (Emory Dr.)	10	10	-	-	8	8	6	6	-	-	-	-	-	48	27
Powell River -Buchanan Ford	-	-	-	9	-	-	-	6	-	-	-	-	-	15	8
Powell River - McDowell Shoal	-	-	-	9	-	-	-	6	-	-	-	4	-	19	11
Copper Creek - Spring Mill Dam	-	10	-	-	-	8	-	-	-	-	-	-	-	18	10
Clinch River - Brooks Island	-	-	-	-	-	8	-	-	-	-	-	-	4	12	4
Clinch River - Kyles Ford	-	-	-	-	-	-	-	-	-	-	-	-	4	4	2
Clinch River - Pendleton Island	-	-	-	-	-	8	-	-	-	-	-	-	4	12	5
Little River above Pistol Cr.	10	-	-	-	8	8	-	-	-	5	-	-	4	35	22
Holston River Drainage															
N. Fk. Holston at Click Is.	-	-	-	9	-	8	-	-	-	-	-	-	4	21	14
N. Fk. Holston above Saltville	-	-	-	-	-	8	6	-	-	-	-	-	-	14	7
Middle Fk. Holston River	-	-	-	9	-	8	-	-	5	-	-	-	4	24	17
Roan Creek (Watauga Dr.)	-	10	-	-	8	8	6	-	-	-	-	-	-	32	21
Doe River (Watauga Dr.)	-	-	-	-	-	8	6	-	5	-	-	-	-	19	12
French Broad River Drainage															
Nolichucky River - Soloman Is.	-	-	-	9	-	8	-	-	-	-	-	-	-	17	9
Nolichucky River - Johnson Is.	-	-	-	-	8	8	-	-	5	-	-	-	-	21	15
North Toe River	-	10	-	9	8	8	6	6	5	-	-	-	-	62	30
Number of entries	9	9	1	11	15	25	11	4	5	2	2	2	10	-	30

BEST COPY AVAILABLE

Table 4. The twenty stream reaches most likely to be suitable for use as designated study reaches in the Cumberlandian Mollusk Conservation Program arranged in order of their evaluation scores.

Score	Stream Reach	Comments
4	Duck River above Leftwich (DRM 160-164)	C Q S
4	Clinch River at Kyles Ford (CRM 189)	C - S
9	Duck River below Lillard Mill Dam (DRM 179)	C - S
12	Clinch River at Brooks Island (CRM 183)	- - -
12	Clinch River at Pendleton Island (CRM 226)	? - S
12	Elk River at Dickey Island (ERM 113)	- - S
14	North Fork Holston River above Saltville (NFHRM 85)	- - S
15	Powell River at Buchanan Ford (PRM 99)	C Q S
17	Nolichucky River at Soloman Island (NRM 3)	- - -
18	Copper Creek near Spring Mill Dam (CCM 2)	- - S
19	Powell River at McDowell Shoal (PRM 106)	C Q @
19	Doe River (Watauga Dr.) (DoRM 1)	- - -
20	Duck River above Shelbyville (DRM 227-248)	- - S
21	North Fork Holston River at Click Island (NFHRM 6)	- - S
21	Nolichucky River at Johnson Island (NRM 14)	- - S
24	Paint Rock River above PRM 12	- - S
24	Middle Fork Holston River above MFHRM 28	- - -
29	Duck River below Shelbyville (DRM 190-215)	- - S
31	Flint River above FRM 20	- - -
32	Sugar Creek near its mouth (SCM 2)	- - -

Comments

C - Conradilla caelata has been taken in this reach within the last five years.

Q - Quadrula intermedia has been taken in this reach within the last five years.

? - C. caelata may occur in this reach, however, adequate collection pressure has not been applied.

S - indicates that this reach has been suggested for selection as a designated study reach.

@ - A similar and relatively close reach (Fletcher Ford - PRM 117) has been suggested as a substitute designated study reach for this impacted area.

(The fifteenth suggested designated study reach is the Buffalo River above Lobelville - BRM 26. It placed 24th in the evaluation.)

Table 5. Tabulation of the Jaccard Coefficients of similarity for qualitative biotic data between Lillards Mill and the other CMCP designated study reaches. Rank order numbers for the study reaches are given below the totals for all categories and for all categories except the mussel data.

Categories	B 79.9	C 189.5	C 227.4	CC 1.9	D 159.4	D 202.2	D 243.1	E 91.4	N 27.8	NFH 6.2	NFH 85.2	PR 60.0	P 99.2	P 117.4
Mussels	.042	.301	.222	.214	.115	.125	.042	.308	.281	.292	.259	.308	.394	.401
Macroinvertebrates	.327	.286	.321	.259	.432	.464	.288	.232	.292	.364	.237	.252	.271	.302
Fish	.635	.527	.486	.464	.758	.771	.348	.478	.438	.492	.391	.537	.486	.486
Zooplankton	.295	.408	.367	.128	.532	.528	.389	.256	.393	.371	.341	.298	.388	.371
Phytoplankton	.381	.453	.478	.362	.597	.627	.622	.524	.551	.448	.501	.421	.508	.508
Periphyton	.421	.431	.468	.459	.535	.488	.558	.501	.404	.501	.396	.475	.488	.468
Totals	2.101	2.606	2.342	1.886	2.969	3.003	2.247	2.299	2.359	2.468	2.125	2.291	2.535	2.556
Ranks	13	3	8	14	2	1	11	9	7	6	12	10	5	4
Totals (minus mussels)	2.059	2.105	2.12	1.672	2.854	2.878	2.205	1.991	2.078	2.176	1.866	1.983	2.141	2.155
Ranks	10	8	7	14	2	1	3	11	9	4	13	12	6	5

BEST COPY AVAILABLE

Table 6. Tabulation of the Jaccard Coefficients of similarity for qualitative biotic data between Kyles Ford and the other CMCP designated study reaches. Rand order numbers for the study reaches are given below the totals for all categories and for all categories except the mussel data.

Categories	B 79.9	C 227.4	CC 1.9	D 159.4	D 179.1	D 202.2	D 243.1	E 91.4	N 27.8	NFH 6.2	NFH 85.2	PR 60.0	P 99.2	P 117.4
Mussels	.031	.273	.229	.118	.501	.059	.001	.229	.242	.212	.265	.229	.528	.611
Macroinvertebrates	.381	.521	.416	.375	.286	.307	.382	.201	.485	.554	.465	.405	.501	.526
Fish	.527	.754	.607	.559	.527	.501	.251	.456	.508	.593	.564	.451	.793	.763
Zooplankton	.333	.415	.257	.371	.408	.412	.294	.184	.278	.459	.289	.405	.475	.351
Phytoplankton	.501	.661	.611	.529	.453	.629	.435	.563	.493	.583	.501	.538	.651	.721
Periphyton	.391	.537	.462	.466	.431	.488	.522	.429	.583	.533	.556	.378	.595	.499
Totals	2.164	3.156	2.582	2.418	2.606	2.396	1.885	2.062	2.589	2.934	2.64	2.406	3.543	3.461
Ranks	12	3	8	9	6	11	14	13	7	4	5	10	1	2
Totals (minus mussels)	2.133	2.883	2.353	2.3	2.105	2.337	1.884	1.833	2.347	2.722	2.375	2.177	3.015	2.85
Ranks	11	2	6	9	12	8	13	14	7	4	5	10	1	3

BEST COPY AVAILABLE

Table 7. Tabulation of the Euclidean distances of dissimilarity for quantitative biotic data between Lillards Mill and the other CMCP designated study reaches. Rank order numbers for the study reaches are given below the totals for all categories and for all categories except the mussel data.

Categories	B 79.9	C 189.5	C 227.4	CC 1.9	D 159.4	D 202.2	D 243.1	E 91.4	N 27.8	NFH 6.2	NFH 85.2	PR 60.0	P 99.2	P 117.4
Mussels	1.945	2.431	1.955	2.061	1.937	1.937	1.951	1.943	1.921	2.021	2.225	2.152	2.262	2.284
Macroinvertebrates	1.141	1.209	1.629	1.208	.842	.969	.858	.881	1.539	1.526	1.537	1.371	1.356	.965
Fish	1.586	1.541	1.688	1.772	1.389	1.336	1.633	1.698	1.804	1.438	1.475	1.711	1.596	1.642
Zooplankton	1.472	1.672	1.552	1.607	1.525	1.691	2.049	1.493	1.841	1.479	1.586	1.636	1.469	1.441
Phytoplankton	1.931	1.883	2.008	1.839	1.801	1.721	2.185	1.785	2.366	1.985	1.891	1.777	1.901	1.861
Periphyton	1.659	1.969	2.091	1.361	1.341	1.371	1.555	1.572	1.706	1.446	1.891	1.663	1.543	1.669
Totals	9.734	10.705	10.923	10.048	8.835	9.225	10.231	9.372	11.177	9.895	10.605	10.31	10.127	9.862
Ranks	4	12	13	7	1	2	9	3	14	6	11	10	8	5
Totals (minus mussels)	7.789	8.274	8.968	7.987	6.898	7.288	8.28	7.429	9.256	7.874	8.38	8.158	7.865	7.578
Ranks	5	10	13	8	1	2	11	3	14	7	12	9	6	4

BEST COPY AVAILABLE

Table 8. Tabulation of the Euclidean distances of dissimilarity for quantitative biotic data between Kyles Ford and the other CMCP designated study reaches. Rank order numbers for the study reaches are given below the totals for all categories and for all categories except the mussel data.

Categories	B 79.5	C 227.4	CC 1.9	D 159.4	D 179.1	D 202.2	D 243.1	E 91.4	H 27.8	NFH 6.2	NFH 85.2	PR 60.0	P 99.2	P 117.4
Mussels	1.867	1.796	1.892	1.858	2.431	1.865	1.865	1.796	1.841	1.899	2.094	2.088	1.899	2.021
Macroinvertebrates	1.414	1.599	1.374	1.285	1.209	1.429	1.064	1.284	1.426	1.487	1.525	1.436	1.306	1.139
Fish	1.329	1.189	1.432	1.344	1.539	1.079	1.182	1.341	1.467	1.036	1.062	1.561	1.052	1.106
Zooplankton	1.241	1.297	1.343	1.396	1.672	1.601	1.987	1.389	1.774	1.251	1.506	1.331	1.186	1.237
Phytoplankton	1.005	.958	.784	1.068	1.833	.816	1.765	.965	1.964	.981	1.043	.761	.966	.958
Periphyton	1.711	2.088	1.643	1.608	1.969	1.661	1.663	1.713	1.683	1.553	1.833	1.781	1.614	1.716
Totals	8.567	8.927	8.468	8.559	10.703	8.451	9.526	8.488	10.155	8.207	9.063	8.928	8.023	8.177
Ranks	8	9	6	7	14	4	12	5	13	3	11	10	1	2
Totals (minus mussels)	6.7	7.131	6.576	6.701	8.272	6.586	7.661	6.692	8.314	6.308	6.969	6.84	6.124	6.156
Ranks	7	11	4	8	13	5	12	6	14	3	10	9	1	2

BEST COPY AVAILABLE

Table 9. Tabulation of the Euclidean distances of dissimilarity for quantitative abiotic data between Lillards Mill and the other CMCP designated study reaches. Rank order numbers for the study reaches are given below the totals.

Categories	B 79.9	C 189.5	C 227.4	CC 1.9	D 159.4	D 202.2	D 243.1	E 91.4	N 27.8	NFH 6.2	NFH 85.2	PR 60.0	P 99.2	P 117.4
Hydrology	1.042	.792	.876	1.769	.973	.727	1.508	.835	1.972	.958	1.825	1.551	.987	.974
Water Quality - Spring	1.935	1.275	1.334	1.057	.931	.692	1.708	1.294	1.729	1.501	1.907	1.509	1.186	1.287
Water Quality -Summer	1.392	1.192	1.366	1.328	1.005	1.221	1.472	.865	1.011	1.522	.996	1.479	1.254	1.247
Totals	4.369	3.259	3.596	4.154	2.929	2.64	4.688	2.994	4.712	3.981	4.728	4.539	3.427	3.508
Ranks	10	4	7	9	2	1	12	3	13	8	14	11	5	6

Table 10. Tabulation of the Euclidean distances of dissimilarity for quantitative abiotic data between Kyles Ford and the other CMCP designated study reaches. Rank order numbers for the study reaches are given below the totals.

Categories	B 79.9	C 227.4	CC 1.9	D 159.4	D 179.1	D 202.2	D 243.1	E 91.4	N 27.8	NFH 6.2	NFH 85.2	PR 60.0	P 99.2	P 117.4
Hydrology	1.448	.898	2.191	1.041	.792	1.368	1.833	1.112	1.605	1.023	2.155	2.094	1.236	1.396
Water Quality - Spring	2.072	.752	.833	1.151	1.275	1.086	1.324	1.216	1.147	.737	.921	1.764	.572	.539
Water Quality -Summer	1.378	.889	.455	1.777	1.192	1.424	1.834	.953	1.201	1.044	.828	1.371	.485	.715
Totals	4.898	2.539	3.501	3.969	3.259	3.798	4.991	3.281	3.953	2.804	3.904	5.229	2.273	2.65
Ranks	12	2	7	11	6	8	13	5	10	4	9	14	1	3

BEST COPY AVAILABLE

Table 11. Standardized canonical discriminant function coefficients for selected hydrologic variables.

Variable Name	Function 1	Function 2	Function 3
Gradient	0.339	-0.105	1.092
Seven Q 10	1.158	-1.604	0.086
Avg. Flow	-1.374	0.470	1.134
Avg. Sediment Load	0.282	1.743	-0.377

Table 12. Standardized canonical discriminant function coefficients for selected water quality variables.

Variable Name	Function 1	Function 2	Function 3
Water Quality - Spring PCA component 1	0.948	0.195	0.391
Water Quality - Spring PCA component 3	-0.965	0.682	0.243
Water Quality - Summer PCA component 1	0.556	0.410	-0.820

BEST COPY AVAILABLE

Table 13. Standardized canonical discriminant function coefficients for selected physical/chemical variables.

Variable Name	Function 1	Function 2	Function 3
Depth	-2.741	-0.862	-0.253
Avg. Velocity	-3.160	0.327	-1.010
20 yr. Flood Flow	1.691	0.267	-0.035
Avg. Sediment Load	2.575	-1.878	0.857
Water Quality - Spring PCA component 1	-1.339	0.343	0.741
Water Quality - Spring PCA component 2	4.019	-0.620	0.532
Water Quality - Spring PCA component 3	2.380	1.828	0.569
Water Quality - Summer PCA component 2	-0.793	1.033	0.802

BEST COPY AVAILABLE

Table 14. Matrix of correlation coefficients derived from comparisons of biotic variables within previously established groups of CMCP designated study reaches. Absolute values equal to, or greater than 0.78 are considered significant.

Parameters	Benthic Diversity	Benthic Density	Fish Diversity	Fish Density	Zooplankton Diversity	Zooplankton Density	Periphyton Diversity	Periphyton Density	Phytoplankton Diversity	Phytoplankton Density	Volatile Solids
Benthic Diversity	1.000										
Benthic Density	0.680	1.000									
Fish Diversity	0.321	-0.039	1.000								
Fish Density	-0.056	0.276	0.140	1.000							
Zooplankton Diversity	-0.024	0.299	-0.408	0.226	1.000						
Zooplankton Density	-0.361	-0.210	-0.770	-0.098	0.349	1.000					
Periphyton Diversity	0.274	0.528	-0.487	0.163	0.801	0.399	1.000				
Periphyton Density	-0.145	-0.227	0.141	-0.015	0.236	0.142	0.103	1.000			
Phytoplankton Diversity	-0.259	0.177	-0.600	0.210	0.817	0.669	0.780	0.354	1.000		
Phytoplankton Density	-0.237	-0.143	-0.559	-0.030	0.380	0.931	0.475	0.344	0.724	1.000	
Volatile Solids	-0.719	-0.386	-0.348	0.192	0.230	0.346	0.038	-0.266	0.244	0.202	1.000

BEST COPY AVAILABLE

Table 15. Biotic variable means, F statistics, and significance levels for the four a priori groups of CMCP designated study reaches.

Parameters	Study Reach Groups 1	2	3	4	Mean	F	P
Benthic Diversity	52.50	44.67	56.00	47.25	50.47	0.587	0.636
Benthic Density	100.73	129.98	205.95	63.30	124.66	3.410	0.057
Fish Diversity	39.00	30.00	29.50	33.75	33.27	1.288	0.327
Fish Density	18.88	18.41	27.84	7.83	18.23	4.252	0.032
Zooplankton Diversity	32.75	23.67	25.25	29.50	28.07	0.775	0.532
Zooplankton Density	720.50	694.33	350.25	2456.00	1079.33	1.044	0.412
Periphyton Diversity	33.25	29.33	29.25	25.25	29.27	1.165	0.370
Periphyton Density	790.80	211.33	176.57	196.72	352.77	0.992	0.432
Phytoplankton Diversity	42.50	39.00	41.00	39.00	40.47	0.056	0.982
Phytoplankton Density	482.20	263.40	224.82	566.97	392.41	0.362	0.782
Volatile Solids	2.75	3.33	2.25	2.00	2.53	1.075	0.400

Table 16. Standardized canonical discriminant function coefficients for selected summary biotic variables.

Variable Name	Function 1	Function 2	Function 3
Number of Fish Species	2.963	1.040	0.120
Zooplankton Density	6.981	-0.170	0.902
Number of Periphyton Species	1.011	0.861	-0.116
Phytoplankton Density	-3.111	0.282	-0.933
Volatile Solids	-0.481	0.589	0.856

BEST COPY AVAILABLE

Table 17 Summary results of discriminant function analysis.

SITE NAME	RIVER & MILE	SITE CLASS	ABIOTIC DISTANCE	ABIOTIC RANK	BIOTIC DISTANCE	BIOTIC RANK	MEAN DISTANCE	SUMMARY RANK
Kyles Ford	CRM 189.5	1	1.2725	-	.7836	-	-	-
Sowell Ford	BRM 159.4	1	1.7624	-	.8798	-	-	-
Lillards Mill	BRM 179.1	1	1.3528	-	1.3392	-	-	-
Buchanan Ford	PRM 99.2	1	1.5403	-	1.1265	-	-	-
Elk River	ERM 91.4	2	8.6343	6	4.6009	9	6.6176	6
Fort Blackmore	CRM 227.4	2	7.4341	5	2.0322	1	4.7331	4
Saltville	MFHRM 85.2	2	9.8788	7	3.6243	5	6.7516	7
Fletcher Ford	PRM 117.4	3	5.2543	4	2.3228	2	3.7886	1
Click Island	MFHRM 6.2	3	4.8135	3	3.8556	6	4.8346	3
Hale Bridge	HRM 27.8	3	4.6847	2	5.5195	11	5.6021	5
Copper Creek	CCRM 1.9	3	3.5449	1	4.6084	10	4.0766	2
Halls Mill	BRM 202.2	4	10.5159	8	3.8992	7	7.2076	8
Dennet Bridge	BRM 243.1	4	11.5641	10	4.4416	8	8.0028	10
Topsy Bridge	BRM 79.9	4	11.3406	9	3.4533	3	7.3971	9
Estill Fork	PRRM 60.0	4	12.6263	11	3.4561	4	8.0412	11

BEST COPY AVAILABLE

Table 18. Final Rankings of Non-Group 1 Designated Study Reaches.

Study Reaches	Rankings After Combined Statistical Analysis	Rankings After *C. caelata* Access Deletions	Rankings After Fish Host Absence Deletions
Group 1 Study Reaches			
Lillards Mill, DRM 179.1		x	
Kyles Ford, CRM 189.5		x	
Sowell Ford, DRM 159.4		x	
Buchanan Ford, PRM 99.2		x	
Other Study Reaches			
Flether Ford, PRM 117.4	1	x	
Click Island, NFHRM 6.2	2	1	1
Elk River, ERM 91.4	3	x	
Fort Blackmore, CRM 227.4	4	x	
Copper Creek, CCRM 1.9	5	x	x
Halls Mill, DRM 202.2	6	2	2
Saltville, NRHRM 85.2	7	3	x
Hale Bridge, NRM 27.8	8	4	3
Topsy Bridge, BRM 79.9	9	5	4
Dement Bridge, DRM 243.1	10*	6	x
Estill Fork, PRRM 60.0	11*	7	x

X = Study reach was disqualified for further study by this criterion.

* = Actual numbers were identical; the DFA ranking was given preference over the similarity ranking.

Table 19. Relative ranking of CMCP study reaches based upon species richness of the freshwater mussel fauna in the inclusive 40-mile stream section. Rankings for each column comparison are indicated within parentheses.

Stream	Mile	Study Reach Name	Species Present		PCA Loadings (PCI)		Composite Ranking
			Total	Cumberlandian	Total (PC_ALL)	Cumberlandian (PC_CUM)	
Buffalo River	79.9	Topsy Bridge	2 (15)	1 (15)	-5.44 (15)	-3.71 (15)	60 (15)
Clinch River	189.5	Kyles Ford	40 (1)	14 (3)	7.84 (1)	3.80 (2)	7 (2)*
Clinch River	227.4	Fort Blackmore	32 (3.5)	12 (4.5)	4.91 (3)	2.59 (4)	15 (4)*
Copper Creek	1.9	Copper Creek	19 (9.5)	11 (6)	-0.68 (9)	1.69 (5)	29.5 (6)*
Duck River	159.4	Sowell Ford	25 (6)	9 (9)	-0.47 (8)	-0.71 (9)	32 (8)
Duck River	179.1	Lillard Mill	29 (5)	10 (7.5)	1.32 (5)	0.29 (6)	23.5 (5)*
Duck River	202.2	Halls Mill	6 (13)	3 (12.5)	-4.46 (13)	-3.15 (13)	51.5 (13)
Duck River	243.1	Dement Bridge	5 (14)	3 (12.5)	-5.26 (14)	-3.26 (14)	54.5 (14)
Elk River	91.4	Elk River	24 (7)	7 (10)	-0.16 (7)	-1.24 (10)	34 (9)
Nolichucky River	27.8	Hale Bridge	19 (9.5)	2 (14)	0.44 (6)	-2.91 (12)	41.5 (11)
North Fork Holston River	6.2	Click Island	9 (12)	5 (11)	-3.05 (12)	-1.26 (11)	46 (12)
North Fork Holston River	85.2	Saltville	17 (11)	10 (7.5)	-2.47 (10)	0.13 (7)	35.5 (10)
Paint Rock River	60.0	Estill Fork	21 (8)	12 (4.5)	-2.58 (11)	-0.18 (8)	31.5 (7)
Powell River	99.9	Buchanan Ford	32 (3.5)	15 (2)	4.62 (4)	3.75 (3)	12.5 (3)*
Powell River	117.4	Fletcher Ford	36 (2)	17 (1)	5.45 (2)	4.17 (1)	6 (1)*

*These study reaches were selected for use in characterizing good Cumberlandian mussel habitat.

Table 20. Pearson correlation coefficients among mussel PCA factors and physical factors of the study reaches.

Factors	Drainage Area	Log Gradient	Average Depth	Average Width	7Q10	Average Flow	DAF	Average Velocity	VAF	20-Year Flood	Suspended Sediment
Drainage Area	1.00										
Log of Gradient	-0.33	1.00									
Average Depth	0.16	0.26	1.00								
Average Width	0.83*	-0.43	-0.04	1.00							
7Q10	0.67*	0.19	0.30	0.36	1.00						
Average Flow	0.99*	-0.37	0.24	0.77*	0.69*	1.00					
Daily Average Flow	0.08	0.23	0.04	-0.12	0.66*	0.11	1.00				
Average Velocity	0.76*	-0.21	0.17	0.42	0.53*	0.81*	0.10	1.00			
Velocity at Average Flow	0.80*	0.16	-0.03	0.45†	0.74*	0.82*	0.36	0.85*	1.00		
20-Year Flood Flow	0.84*	-0.13	0.34	0.68*	0.68*	0.83*	0.29	0.64*	0.60*	1.00	
Suspended Sediment at Average Flow	0.57*	0.26	0.08	0.34	0.84	0.56*	0.58*	0.54*	0.68*	0.57*	1.00
PC_ALL	0.52*	-0.18	0.05	0.48†	0.23	0.47†	0.09	0.23	0.32	0.41	0.26
PC_CUM	0.09	-0.10	-0.12	0.17	-0.20	0.03	-0.10	-0.12	-0.08	0.01	-0.06

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

BEST COPY AVAILABLE

Table 21. Partial correlation coefficients for selected physical factors to mussel PCA factors controlled for the combined effect of drainage area and average flow. Uncontrolled correlation coefficients are presented in parentheses.

Mussel Factors	Log Gradient	Width	7Q10	Velocity at Average Flow	Suspended Sediment At Average Flow
PC_ALL	-0.11 (-0.18)	-0.10 (0.48†)	-0.15 (0.23)	-0.10 (0.32)	-0.06 (0.26)
PC_CUM	-0.21 (-0.10)	-0.06 (0.17)	-0.32 (-0.20)	-0.16 (-0.08)	-0.15 (-0.06)

†Significant at the 90 percent confidence level.

Table 22. Pearson correlation coefficients for chemical factors and mussel PCA factors

Factor	11 Months		Summer-Fall		Winter-Spring	
	PC_ALL	PC_CUM	PC_ALL	PC_CUM	PC_ALL	PC_CUM
Alkalinity	0.42	0.71*	0.44	0.72*	0.32	0.59*
Aluminum	0.59*	0.58*	0.20	0.06	0.56*	0.56*
Ammonia	-0.34	-0.30	-0.25	-0.23	-0.32	-0.30
BOD (5 days)	-0.18	-0.04	-0.30	-0.28	-0.15	-0.001
Cadmium	-0.31	-0.09	-0.11	0.14	-0.36	-0.20
Calcium	0.28	0.52*	0.38	0.62*	0.20	0.40
Chloride	-0.15	-0.08	-0.15	-0.08	-0.13	-0.06
Chromium	0.38	0.28	-0.28	-0.32	0.52*	0.44†
Conductivity	0.38	0.57*	0.38	0.54*	0.38	0.61*
COD	0.33	0.38	-0.20	-0.03	0.52*	0.49†
Copper	-0.29	-0.20	0.59*	0.55*	-0.47†	-0.39
Dissolved Oxygen	0.33	0.43	0.37	0.45†	0.20	0.23
Hardness	0.53*	0.78*	0.54*	0.77*	0.45†	0.70*
Iron (dissolved)	-0.44	-0.42	-0.44†	-0.39	0.11	-0.06
Iron (total)	0.54*	0.60*	-0.08	0.12	0.54*	0.54*
Lead	0.22	0.17	-0.15	-0.06	0.32	0.22
Manganese (dissolved)	-0.34	-0.32	-0.36	-0.33	-0.27	-0.29
Manganese (total)	-0.18	-0.18	-0.36	-0.34	0.005	-0.02
Mercury	-0.13	0.01	-0.07	-0.12	-0.10	0.21
Nitrogen (organic)	-0.30	-0.26	-0.24	-0.24	-0.27	-0.27
Nitrogen (NO_2 and NO_3)	0.23	0.13	0.12	0.01	0.36	0.28
pH	0.22	0.26	0.14	0.22	0.34	0.34
Phosphorus (total)	-0.24	-0.37	-0.19	-0.32	-0.18	-0.36
Residue (dissolved)	0.62*	0.56*	0.21	-0.05	0.56*	0.58*
Residue (total)	0.39	0.56*	0.39	0.54*	0.35	0.56*
Selenium	0.57*	0.46†	0.53*	0.42	0.33	0.34
Sodium	0.10	0.17	0.06	0.14	0.15	0.21
Sulfate	0.76*	0.82*	0.75*	0.80*	0.77*	0.85*
Temperature	-0.08	-0.20	0.16	-0.09	-0.42	-0.32
TOC	-0.33	-0.24	-0.40	-0.30	0.03	0.02
Zinc	-0.32	-0.14	-0.01	-0.03	-0.32	-0.14
Number of apparent correlations	6	10	5	8	8	10

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 23. Pearson correlation coefficients among mussel PCA factors and hardness group factors

Factors	Alk	Ca	Chl	Cond	Hard	T Res	D Res	Sod	Sul
Alkalinity	1.00								
Calcium	0.75*	1.00							
Chloride	0.06	0.45†	1.00						
Conductivity	0.62*	0.76*	0.74*	1.00					
Hardness	0.86*	0.85*	0.41	0.91*	1.00				
Residue (Total)	0.58*	0.75*	0.73*	0.99*	0.89*	1.00			
Residue (Diss)	0.06	-0.06	-0.19	0.17	0.22	0.24	1.00		
Sodium	0.14	0.48†	0.94*	0.84*	0.55*	0.85*	0.12	1.00	
Sulfate	0.39	0.40	0.14	0.63*	0.68*	0.68*	0.79*	0.45†	1.00
PC_ALL	0.42	0.28	-0.15	0.38	0.53*	0.39	0.62*	0.10	0.76*
PC_CUM	0.71*	0.52*	-0.08	0.57*	0.78*	0.57*	0.56*	0.17	0.82*

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 24. Partial correlation coefficients for selected chemical factors in the hardness group to mussel PCA factors controlled for the effect of alkalinity. The uncontrolled correlation coefficients are presented in parentheses.

Mussel Factors	Calcium	Chloride	Conductivity	Total Residue	Dissolved Residue	Sodium	Sulfate
PC_ALL	-0.05 (0.28)	-0.19 (-0.15)	0.22 (0.38)	0.20 (0.39)	0.61* (0.62*)	0.05 (0.10)	0.74* (0.76*)
PC_CUM	-0.03 (0.52*)	-0.18 (-0.08)	0.33 (0.57*)	0.25 (0.57*)	0.75* (0.56*)	0.10 (0.17)	0.87* (0.82*)

*Significant at the 95 percent confidence level.

Table 25. Partial correlation coefficients for selected hardness group factors controlled for the effect of sulfate. The uncontrolled correlation coefficients are presented in parentheses.

Mussel Factors	Alkalinity	Conductivity	Total Residue	Dissolved Residue	Sodium
PC_ALL	0.21 (0.42)	-0.19 (0.38)	-0.25 (0.39)	0.06 (0.62*)	-0.41 (0.10)
PC_CUM	0.74* (0.71*)	0.11 (0.57*)	0.005 (0.57*)	-0.24 (0.56*)	-0.40 (0.17)

*Significant at the 95 percent confidence level.

Table 26. Pearson correlation coefficients among mussel PCA factors and metals group factors for the full 11-month sampling period and the summer-fall and winter-spring subsets

Factors	Al	Cd	Cr	Cu	DFe	TFe	Pb	DMn	TMn	Hg	Ph	Se	Zn
Aluminum	1.00												
Cadmium	-0.13	1.00											
Chronium	0.68*	0.05	1.00										
Copper	-0.14	-0.01	-0.37	1.00									
Iron (Diss)	-0.20	-0.16	-0.25	-0.18	1.00								
Iron (Total)	0.95*	-0.05	0.66*	-0.21	-0.12	1.00							
Lead	0.55*	-0.34	0.52*	-0.19	0.16	0.52*	1.00						
Manganese (Diss)	-0.55	-0.18	-0.19	-0.11	0.88*	-0.07	0.12	1.00					
Manganese (Total)	0.13	-0.23	0.01	-0.15	0.78*	0.19	0.26	0.95*	1.00				
Mercury	-0.21	0.03	-0.36	0.03	-0.19	-0.16	0.15	-0.21	-0.23	1.00			
Phosphorus	-0.22	-0.15	-0.15	-0.01	-0.03	-0.26	0.36	-0.07	-0.09	0.46†	1.00		
Selenium	0.07	-0.19	0.17	0.01	-0.10	0.05	0.10	-0.12	-0.12	-0.27	-0.29	1.00	
Zinc	-0.02	0.78*	0.06	0.34	-0.18	-0.09	-0.26	-0.12	-0.13	-0.14	-0.10	-0.19	1.00
PC_ALL	0.59*	-0.31	0.38	-0.29	-0.44	0.54*	0.22	-0.34	-0.18	-0.13	-0.24	0.57*	-0.32
PC_CUM	0.58*	-0.09	0.27	-0.20	-0.42	0.60*	0.17	-0.32	-0.18	0.01	-0.37	0.46†	-0.15
Summer-Fall Only													
PC_ALL	0.20	-0.11	-0.28	0.59*	-0.44†	-0.08	-0.15	-0.36	-0.36	-0.07	-0.19	0.53*	-0.01
PC_CUM	0.06	0.14	-0.32	0.55*	-0.39	0.12	-0.06	-0.33	-0.34	-0.12	-0.32	0.42	-0.03
Winter-Spring Only													
PC_ALL	0.56*	-0.36	0.52*	-0.47†	0.11	0.54*	0.32	-0.27	0.004	-0.10	-0.18	0.33	-0.32
PC_CUM	0.56*	-0.20	0.44†	-0.39	-0.06	0.54*	0.22	-0.29	-0.02	0.21	-0.36	0.33	-0.15

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 27. Partial correlation coefficients for selected metals group factors to mussel PCA factors controlled for the effect of total iron. The uncontrolled correlation coefficients are presented in parentheses.

Mussel Factors	Chromium	Copper	Dissolved Iron	Selenium
Summer-Fall Data				
PC_ALL	-0.29 (-0.28)	0.68* (0.59*)	-0.44 (-0.44†)	0.52† (0.53*)
PC_CUM	-0.31 (-0.32)	0.55* (0.55*)	-0.41 (-0.39)	0.45 (0.42)
Winter-Spring Data				
PC_ALL	0.16 (0.52*)	-0.47† (-0.47†)	0.26 (0.11)	0.11 (0.33)
PC_CUM	-0.02 (0.44)	-0.37 (-0.39)	0.06 (-0.06)	0.11 (0.34)

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 28. Person correlation coefficients among mussel PCA factors and "others" group factors for the full 11-month sampling period and the summer-fall and winter-spring subsets

Factors	NH_3	BOD	COD	DO	N (Org)	NO_2NO_3	pH	Temp	TOC
Ammonia	1.00								
BOD	0.13	1.00							
COD	0.24	0.38	1.00						
DO	-0.08	-0.07	0.01	1.00					
N (Organic)	0.28	0.86*	0.45†	-0.39	1.00				
NO_2, NO_3	-0.39	-0.58*	-0.20	-0.15	-0.47†	1.00			
pH	0.13	-0.47†	-0.01	0.03	-0.31	0.47†	1.00		
Temperature	-0.52*	0.04	-0.20	-0.31	0.22	0.34	-0.17	1.00	
TOC	0.38	0.63*	0.55*	-0.44†	0.88*	-0.20	-0.03	0.20	1.00
PC_ALL	-0.34	-0.18	0.33	0.33	-0.30	0.23	0.22	-0.08	-0.33
PC_CUM	-0.30	-0.04	0.38	0.43	-0.26	0.13	0.26	-0.20	-0.24
Summer-Fall Only									
PC_ALL	-0.25	-0.30	-0.20	0.37	-0.24	0.12	0.14	0.16	-0.40
PC_CUM	-0.23	-0.28	-0.03	0.45†	-0.24	0.004	0.22	-0.09	-0.30
Winter-Spring Only									
PC_ALL	-0.32	-0.15	0.52*	0.20	-0.27	0.36	0.34	-0.43	0.03
PC_CUM	-0.30	-0.001	0.49†	0.23	-0.27	0.28	0.34	-0.32	0.02

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 29. Partial correlation coefficients for selected chemical factors in the "others" group to mussel PCA factors controlled for the effect of organic nitrogen. The uncontrolled correlation coefficients are presented in parentheses

Mussel Factors	BOD	COD	DO	NO_2/NO_3	pH	TOC
			Summer-Fall Data			
PC_ALL	-0.20 (-0.30)	0.02 (-0.20)	0.30 (0.37)	0.04 (0.12)	0.21 (0.14)	-0.39 (-0.40)
PC_CUM	-0.17 (-0.28)	0.35 (-0.03)	0.39 (0.45†)	-0.08 (0.004)	0.30 (0.22)	-0.18 (-0.30)
			Winter-Spring Data			
PC_ALL	0.14 (-0.15)	0.60* (0.52*)	0.05 (0.20)	0.28 (0.36)	0.22 (0.34)	0.35 (0.03)
PC_CUM	0.43 (-0.001)	0.56* (0.49†)	0.09 (0.22)	0.18 (0.28)	0.22 (0.34)	0.34 (0.02)

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 30. Pearson correlation coefficients among mussel PCA factors and biological factors. Only the bacteriological factors were collected monthly, thus permitting separation into summer-fall and winter-spring subsets.

Factors	FCOL	TCOL	STREP	Mac De	Mac Ta	Phy De	Phy Ta	Zoo De	Zoo Ta	Peri De	Peri Ta	BF De	BF Ta	Fish De	Fish Ta
FCOL	1.00														
TCOL	-0.29	1.00													
STREP	0.17	0.26	1.00												
Mac De	-0.08	-0.05	-0.01	1.00											
Mac Ta	0.05	0.05	-0.14	0.75*	1.00										
Phy De	0.02	-0.03	-0.07	-0.03	0.35	1.00									
Phy Ta	0.06	-0.20	-0.03	0.29	0.36	0.78*	1.00								
Zoo De	-0.08	0.46†	0.14	-0.06	0.36	0.71*	0.40	1.00							
Zoo Ta	-0.08	0.37	0.004	0.04	0.45†	0.56*	0.37	0.69*	1.00						
Peri De	-0.12	0.23	0.01	0.04	0.17	0.12	0.12	0.09	0.64*	1.00					
Peri Ta	-0.08	0.24	0.29	0.07	-0.17	-0.12	0.16	0.16	-0.16	-0.01	1.00				
BF De	-0.04	-0.31	-0.15	0.60*	0.11	-0.15	0.32	-0.42	-0.51†	-0.36	0.31	1.00			
BF Ta	-0.16	-0.07	-0.20	0.51†	0.10	-0.38	-0.15	-0.46†	-0.52*	-0.24	0.22	0.78*	1.00		
Fish De	0.17	-0.34	-0.10	0.41	-0.06	-0.13	0.34	-0.40	-0.34	-0.12	0.29	0.65*	0.26	1.00	
Fish Ta	-0.46†	0.12	-0.24	-0.18	-0.30	-0.34	-0.24	-0.35	-0.04	0.58*	0.07	-0.17	-0.05	0.01	1.00
PC_ALL	0.17	-0.45†	-0.47†	0.06	-0.07	-0.22	0.12	-0.42	-0.34	0.08	0.40	0.37	0.23	0.52*	0.41
PC_CUM	0.14	-0.32	-0.49†	-0.04	-0.21	-0.31	-0.12	-0.35	-0.35	0.06	0.46†	0.30	0.37	0.42	0.35
Summer-Fall Only															
PC_All	-0.36	-0.66*	-0.50†												
PC_CUM	-0.46†	-0.52*	-0.39												
Winter-Spring Only															
PC_ALL	0.32	0.38	-0.11												
PC_CUM	0.46	0.32	-0.20												

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 31. Partial correlation coefficients for selected biological factors to mussel PCA factors controlled for the effect of zooplankton taxa. The uncontrolled correlation coefficients are presented in parentheses

Mussel Factors	Total Coliform	Macrophyte Density	Phytoplankton Density	Periphyton Taxa	Bottom Fauna Density	Fish Density	Fish Taxa
PC_ALL	-0.38 (-0.45†)	0.08 (0.06)	-0.04 (-0.22)	0.37 (0.40)	0.24 (0.37)	0.46† (0.52*)	0.42 (0.41)
PC_CUM	-0.21 (-0.32)	-0.02 (-0.04)	-0.14 (-0.31)	0.43 (0.46†)	0.16 (0.30)	0.34 (0.42)	0.36 (0.35)

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Tabel 32. Ecological factors which yielded significant correlations with mussel species richness (PCA) factors

Key Factors	Close Correlates	Relationships to PC_ALL	Relationships to PC_CUM
Physical Factors			
Drainage Area		0.52*	0.09
	Average Flow (0.99*)	0.47†	0.03
	Average Width (0.83*)	0.48†	0.17
Chemical Factors			
Alkalinity		0.42	0.71*
	Hardness (0.86*)	0.53*	0.78*
	Calcium (0.75*)	0.28	0.52*
	Conductivity (0.62*)	0.38	0.57*
	Total Residue (0.58*)	0.39	0.57*
Sulfate		0.76*	0.82*
	Dissolved Residue (0.79*)	0.62*	0.56*
	Hardness (0.68*)	0.53*	0.78*
	Total Residue (0.68*)	0.39	0.57*
	Conductivity (0.63*)	0.38	0.57*
Aluminum		0.56*W	0.56*W
	Total Iron (0.95*)	0.54*W	0.54*W
	Chromium (0.63*)	0.52*W	0.44†W
Copper		-0.47†W	-0.39
		-0.59†S	0.55*S
Dissolved Iron		-0.44†S	-0.39S
Selenium		0.53*S	0.42S
Chemical Oxygen Demand		0.52*W	0.49†W
Dissolved Oxygen		0.37S	0.45†S
Biological Factors			
Fecal Streptococcus		-0.50†S	-0.39S
	Fecal Coliforms (0.50†S)	-0.36S	-0.46†S
Total Coliforms		-0.66*S	-0.52*S
Periphyton Taxa		0.40	0.46†
Fish Density		0.52*	0.42

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

SSummer-fall subset analysis.

WWinter-spring subset analysis.

Table 33. Pearson correlation coefficients among mussel factors and key environmental factors during the summer-fall season (May and July-October)

	D Area	Alk	Sul	Cu	D Fe	DO	Se	T Coli	Strep	Peri Ta	Fish De
Drainage Area	1.00										
Alkalinity	-0.09	1.00									
Sulfate	0.02	0.42	1.00								
Copper	0.61*	0.49†	0.30	1.00							
Dissolved Iron	-0.42	-0.46†	-0.26	-0.28	1.00						
Dissolved Oxygen	0.04	0.46†	0.40	0.42	-0.16	1.00					
Selenium	0.43	0.15	0.31	0.11	-0.16	0.22	1.00				
Total Coliform	-0.72*	-0.35	-0.48†	-0.78*	0.40	-0.40	-0.39	1.00			
Fecal Streptococcus	-0.28	0.17	-0.48†	-0.06	0.06	0.22	0.19	0.30	1.00		
Periphyton Taxa	-0.05	0.65*	0.32	0.17	-0.41	0.48†	0.03	-0.09	0.22	1.00	
Fish Density	0.37	0.27	0.55*	0.57*	-0.41	0.51†	-0.19	-0.56*	-0.24	0.29	1.00
PC_ALL	0.54*	0.44	0.75*	0.59*	-0.44†	0.37	0.53*	-0.66*	-0.50*	0.40	0.52*
PC_CUM	0.16	0.72*	0.80*	0.55*	-0.39	0.45†	0.42	-0.52*	-0.39	0.46†	0.42

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 34. Pearson correlation coefficients among mussel factors and key environmental factors during the winter-spring season (November-April).

Factors	D Area	Alk	Sul	Al	Cu	COD	Peri Ta	Fish De
Drainage Area	1.00							
Alkalinity	0.05	1.00						
Sulfate	0.05	0.32	1.00					
Aluminum	-0.02	-0.06	0.76*	1.00				
Copper	-0.30	0.18	-0.08	-0.15	1.00			
Chemical Oxygen Demand	-0.06	-0.07	0.73*	0.63*	-0.17	1.00		
Periphyton Taxa	-0.05	0.36	0.25	0.21	-0.17	0.28	1.00	
Fish Density	0.37	0.04	0.53*	0.64*	-0.26	0.57*	0.29	1.00
PC_ALL	0.54*	0.32	0.77*	0.56*	-0.47†	0.52*	0.40	0.52*
PC_CUM	0.16	0.59*	0.85*	0.56*	-0.39	0.49†	0.46†	0.42

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 35. Partial correlation coefficients for key factors during the summer-fall season to mussel PCA factors controlled for the separate effects of drainage area, alkalinity, and sulfate. Uncontrolled correlation coefficients are presented in parenthesis.

Factors	D Area	Alk	Sul	Cu	DFe	DO	Se	T Coli	Strep	Peri Ta	Fish De
Controlled for Drainage Area											
PC_ALL	- (0.54*)	0.75* (0.44)	0.88* (0.75*)	0.50† (0.59*)	-0.29 (-0.44†)	0.45 (0.37)	0.39 (0.53*)	-0.54† (-0.66*)	-0.44 (-0.50*)	0.54† (0.40)	0.41 (0.52*)
PC_CUM	- (0.16)	0.82* (0.72*)	0.87* (0.80*)	0.56* (0.55*)	-0.35 (-0.39)	0.43 (0.45†)	0.42 (0.42)	-0.56* (-0.52*)	-0.44 (-0.39)	0.45 (0.46†)	0.39 (0.42)
Controlled for Alkalinity											
PC_ALL	0.73* (0.54*)	- (0.44)	0.60* (0.75*)	0.62* (0.59*)	-0.22 (-0.44†)	0.23 (0.37)	0.48 (0.53*)	-0.71* (-0.66*)	-0.63* (-0.50*)	0.09 (0.40)	0.44 (0.52*)
PC_CUM	0.39 (0.16)	- (0.72*)	0.72* (0.80*)	0.48† (0.55*)	0.04 (-0.39)	0.22 (0.45†)	0.41 (0.42)	-0.53† (-0.52*)	-0.76* (-0.39)	-0.15 (0.46†)	0.29 (0.42)
Controlled for Sulfate											
PC_ALL	0.80* (0.54*)	0.12 (0.44)	- (0.75*)	0.58* (0.59*)	-0.37 (-0.44†)	0.07 (0.37)	0.48† (0.53*)	-0.51† (-0.66*)	-0.28 (-0.50*)	0.22 (0.40)	0.17 (0.52*)
PC_CUM	0.29 (0.16)	0.52† (0.72*)	- (0.80*)	0.37 (0.55*)	-0.27 (-0.39)	0.04 (0.45†)	0.40 (0.42)	-0.03 (-0.52*)	-0.16 (-0.39)	0.20 (0.46†)	-0.18 (0.42)

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 36. Partial correlation coefficients for key factors during the winter-spring season to mussel PCA factors controlled for the separate effects of drainage area, alkalinity and sulfate. Uncontrolled correlation coefficients are presented in parentheses.

Factors	D Area	Alk	Sul	Al	Cu	COD	Peri Ta	Fish De
Controlled for Drainage Area								
PC_ALL	- (0.54*)	0.47 (0.32)	0.88* (0.77*)	0.68* (0.56*)	-0.43 (-0.47†)	0.68* (0.52*)	0.54† (0.40)	0.41 (0.52*)
PC_CUM	- (0.17)	0.61* (0.59*)	0.91* (0.85*)	0.61* (0.56*)	-0.33 (-0.39)	0.60* (0.49†)	0.45 (0.46†)	0.39 (0.42)
Controlled for Alkalinity								
PC_ALL	0.57* (0.54*)	- (0.32)	0.71* (0.77*)	0.60* (0.56*)	-0.68* (-0.47†)	0.53† 90.52*)	0.36 (0.40)	0.56* (0.52*)
PC_CUM	0.17 (0.17)	- (0.59*)	0.87* (0.85*)	0.73* (0.56*)	-0.64* (-0.39)	0.63* (0.49†)	0.35 (0.46†)	0.50† (0.42)
Controlled for Sulfate								
PC_ALL	0.78* (0.54*)	0.08 (0.32)	- (0.77*)	-0.05 (0.56*)	-0.64* (-0.47†)	-0.06 (0.52*)	0.32 (0.40)	0.20 (0.52*)
PC_CUM	0.27 (0.17)	0.44 (0.59*)	- (0.85*)	-0.28 (0.56*)	-0.57* (-0.39)	-0.27 (0.49†)	0.38 (0.46†)	-0.19 (0.42)

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 37. Pearson correlation coefficients for key water quality factors with the mussel factors excluding data from both Powell River study reaches. Correlation coefficients based on all 15 study reaches are presented in parentheses.

Factors	Summer-Fall PC_ALL	Summer-Fall PC_CUM	Winter-Spring PC_ALL	Winter-Spring PC_CUM
Alkalinity	0.36 (0.44)	0.72* (0.72*)	0.37 (0.32)	0.73* (0.59*)
Aluminum	0.33 (0.20	-0.06 (0.06)	0.38 (0.56*)	0.25 (0.56*)
Chemical Oxygen Demand	0.31 (-0.20)	0.18 (-0.03)	-0.11 (0.52*)	0.13 (0.49†)
Copper	-0.45 (0.59*)	-0.36 (0.55*)	0.61* (-0.47†)	0.61* (-0.39)
Dissolved Oxygen	0.34 (0.37)	0.42 (0.45†)	0.23 (0.20)	0.30 (0.23)
Dissolved Iron	0.34 (-0.44†)	0.20 (-0.39)	-0.46 (0.11)	-0.42 (-0.06)
Selenium	0.16 (0.53*)	0.11 (0.42)	0.62* (0.33)	0.54† (0.34)
Sulfate	0.70* (0.75*)	0.77* (0.80*)	0.68* (0.77*)	0.67* (0.85*)

*Significant at the 95 percent confidence level.

†Significant at the 90 percent confidence level.

Table 38. Summary of relationships of environmental factors to mussel habitat characterization.

Key Factors	Correlated Factors	Relationships	Comments
Alkalinity	Calcium, conductivity, total residue, dissolved oxygen (S), periphyton taxa	Positively to Cumberlandian species richness	Expected for all mussels, likely related to calcium carbonate availability
Copper		Positively to both total and Cumberlandian species richness in summer-fall Negatively to total species richness in winter-spring	
Dissolved Iron		Negatively to total species richness in summer-fall	
Drainage Area	Average flow, average width	Positively to total speciesrichness	Expected for all mussels, likely related to niche and fish host availability
Fecal Coliforms		Negatively to Cumberlandian species richness in summer-fall	Data set incomplete and extremely variable, could indicate detrimental effects of high bacterial levels
Fish Density		Positively to total species richness	Logical if fish density is important in fish host interactions
Fecal Streptococcus		Negatively to total species richness in summer-fall	Data set incomplete and extremely variable, could indicate indicate detrimental effects of high bacterial levels
Selenium		Positively to total species richness in summer-fall	
Sulfate	Dissolved residue, hardness, aluminum (W), total iron (W), chromium (W), chemical oxygen demand (W)	Positively to both total and Cumberlandian species richness	Contrary to expectations; could indicate importance of high electrolyte levels or buffering capacity
Total Coliforms		Negatively to both total and Cumberlandian species richness in summer-fall	Data set incomplete and extremely variable, could indicate detrimental effects of high bacterial levels

S=Summer-fall subset analysis.
W=Winter-spring subset analysis.

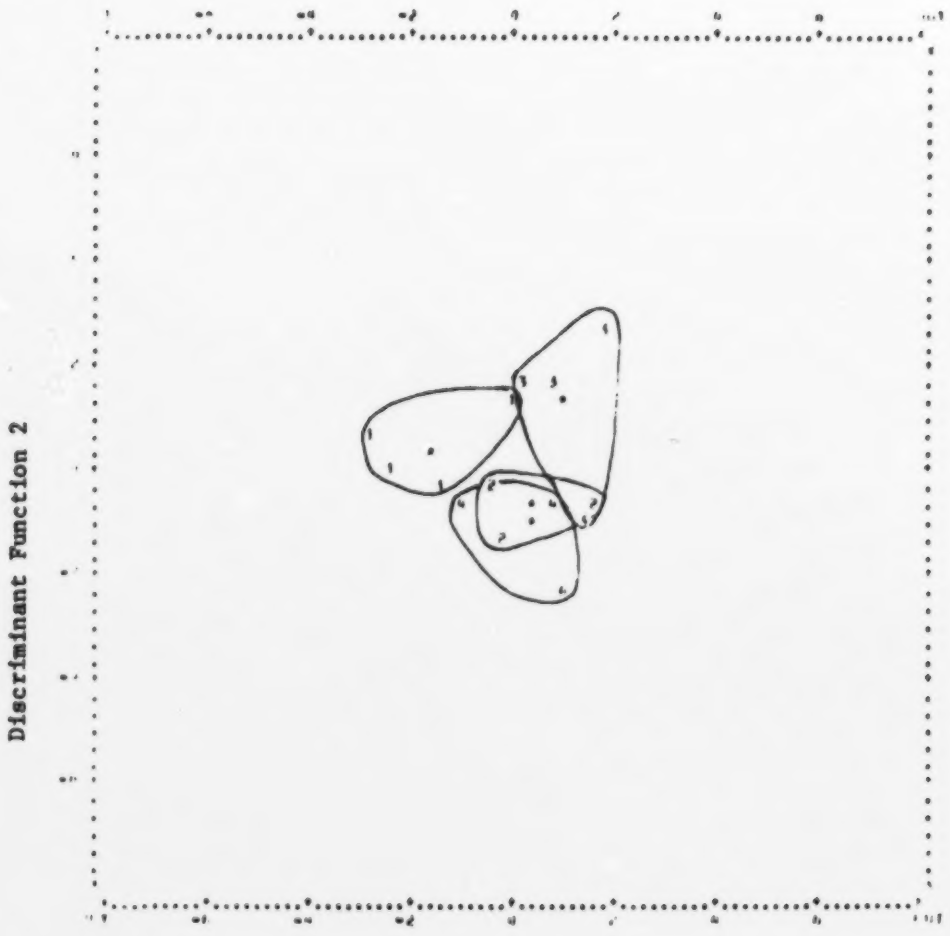

Figure 1. Scatter plot of the four groups of CMCP study reaches and the group centroids(*) as separated by the first and second discriminant functions of the analysis of hydrologic data. In this and each of the following three plots, the first discriminant function is plotted along the horizontal axis and the second function is plotted along the vertical axis.

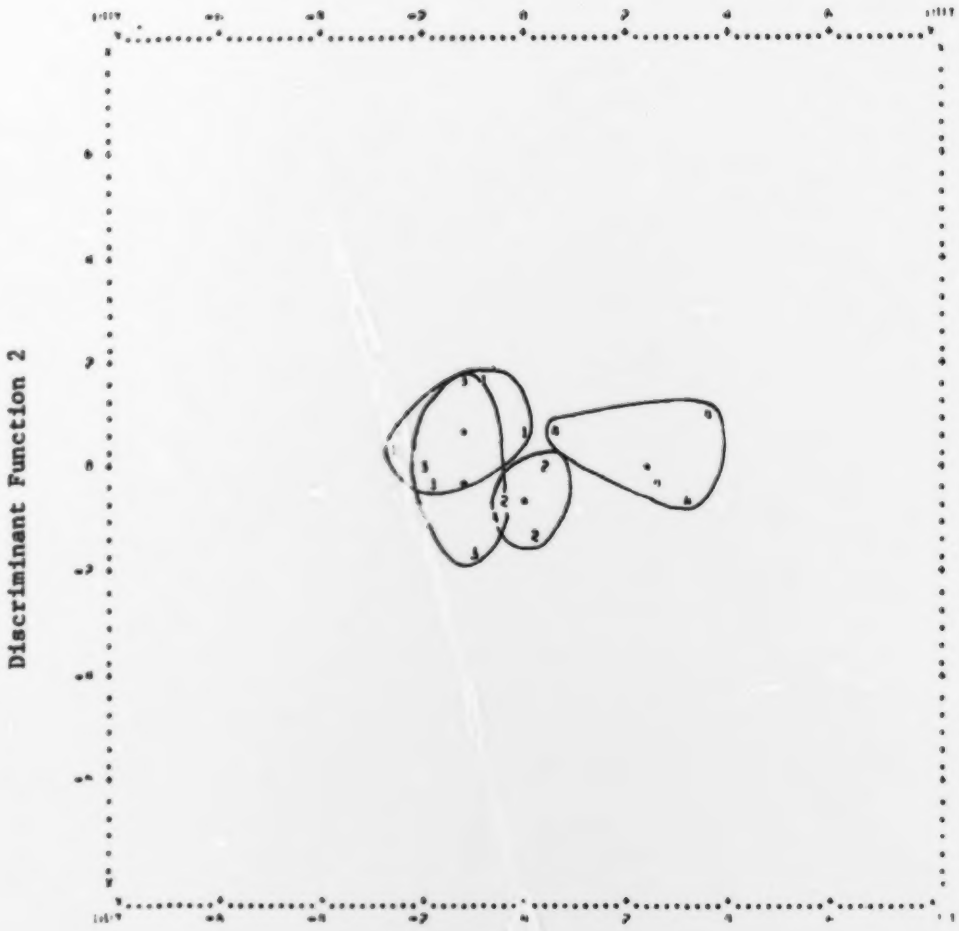

Figure 2. Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discriminant functions of the analysis of water quality data.

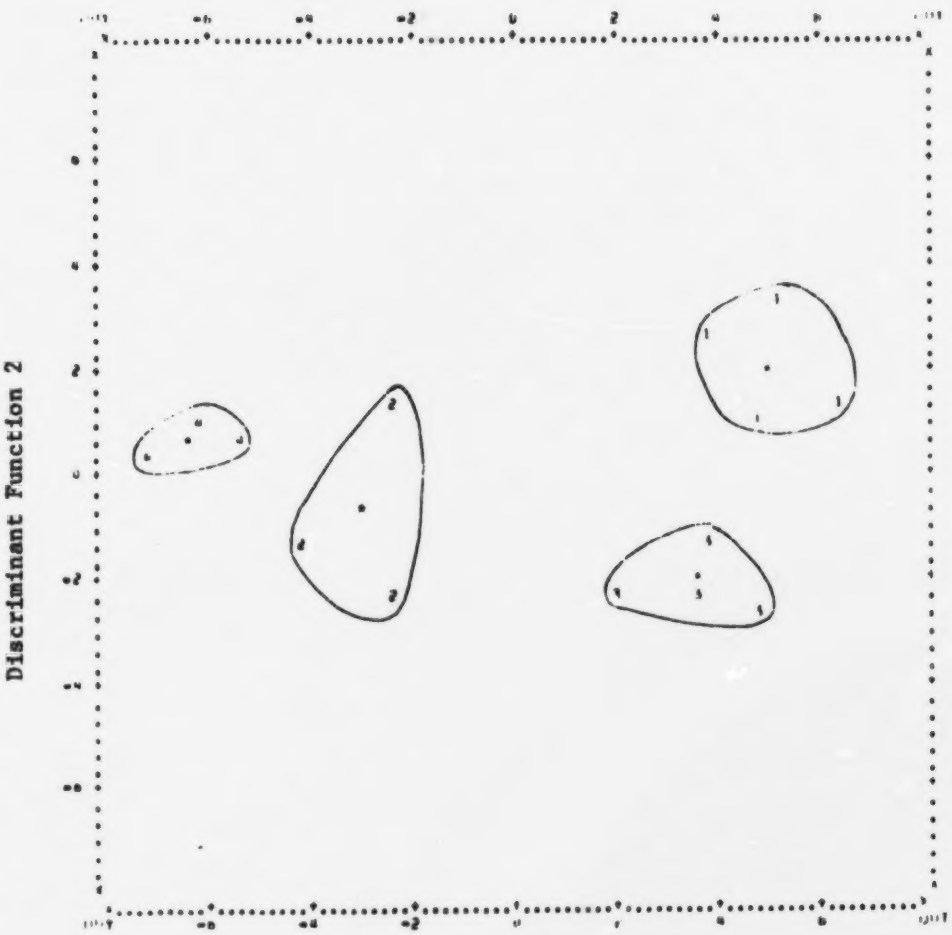

Figure 3. Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discriminant functions of the analysis of hydrologic and water quality data combined.

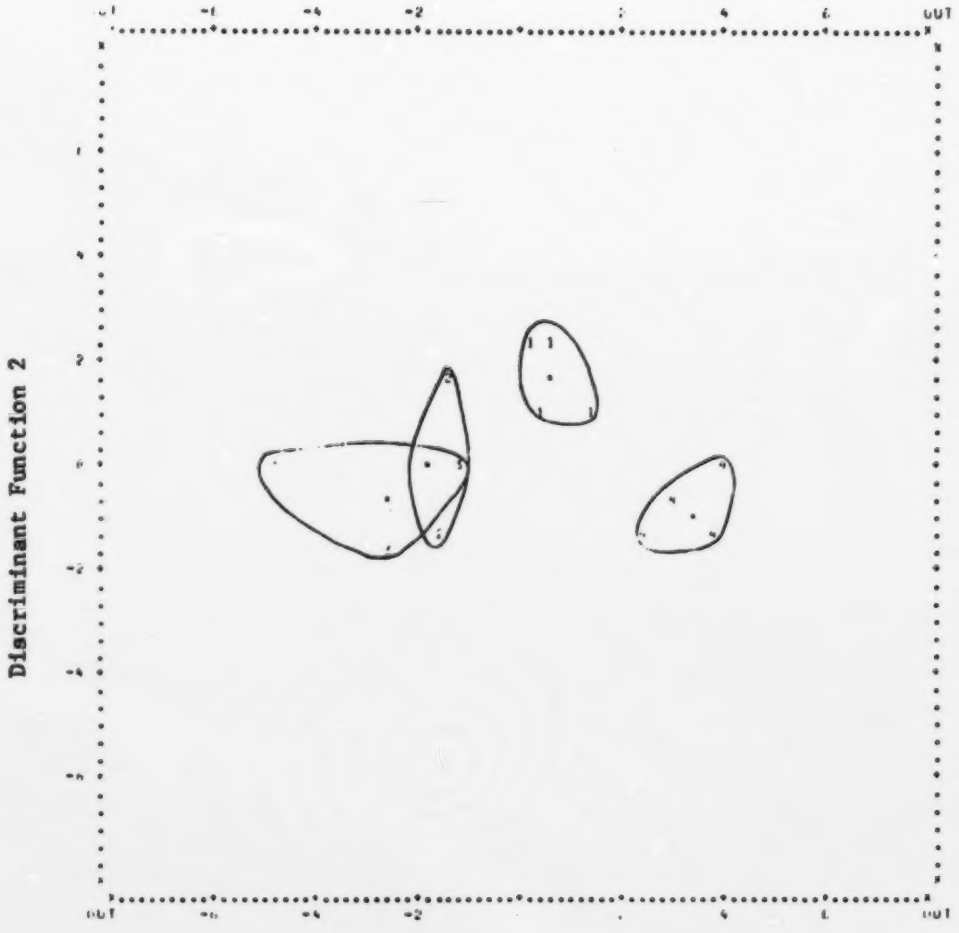

Figure 4. Scatter plot of the four groups of CMCP study reaches and the group centroids (*) as separated by the first and second discriminant functions of the analysis of biotic data (excluding mussel information).

LITERATURE CITED

Allen, E. B. 1982. Water and nutrient competition between Salsola kali and two native grass species Agropyron smithii and Bouteloua gracilis. Ecology, 63:732-741.

Blackith, R. E. and R. A. Reyment. 1971. Multivariate Morphometrics. Academic Press, London and New York. 412p.

Boesch, D. F. 1977. Application of Numerical Classification in Ecological Investigations of Water Pollution. EPA-600/3-77-033. Corvallis Environmental Research Laboratory, Office of Research and Development U.S. Environmental Protection Agency, Corvallis, OR. 115 p.

Casselman, J. M., J. J. Collins, E. J. Crossman, P. E. Ihssen, and G. R. Spangler. 1981. Lake whitefish (Coregonus clupeaformis) stocks of the Ontario waters of Lake Huron. Canadian Journal of Fisheries and Aquatic Sciences, 38:1772-1789.

Crossman, J. S., J. Cairns, Jr., and R. L. Kaesler. 1973. Aquatic Invertebrate Recovery in The Clinch River Following Hazardous Spills and Floods. Bulletin 63, Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 66

Elliott, J. M. 1971. Some Methods for the Statistical Analysis of Samples of Benthic Invertebrates. Scientific Publication No. 25, Freshwater Biological Association. Ambleside, Westmorland LA 22 OLP. 148 p.

Goldstein, R. A. and D. F. Grigal. 1972. Definition of vegetation structure by canonical analysis. Journal of Ecology. 60:277-284.

Gower, J. C. 1966. A Q-technique for the calculation of canonical variates. Biometrika. 53:588-589.

Gower, J. C. 1967. Multivariate Analysis and Multidimensional Geometry. The Statistician. 17:13-28.

Green, R. H. 1979. Sampling Desigh and Statistical Methods for Environmental Biologists. John Wiley and Sons. New York. 257 p.

Ihssen, P. E., D. O. Evans, W. J. Christie, J. A. Reckman, and R. L. DesJardine. 1981. Life history, morphology, and electrophoretic characteristics of five allopatric stocks of lake whitefish (Coregonus clupeaformis) in the Great Lakes Region. Canadian Journal of Fisheries and Aquatic Sciences. 38:1790-1807.

Neves, R. J., G. B. Pardue, E. F. Benfield and S. D. Dennis. 1980. An Evaluation of Endangered Mollusks in Virginia. Final Report, Project No. E-F-1, Fish Division, Virginia Commission of Game and Inland Fisheries. 140 p.

Nie, N. H., C. H. Hall, J. G. Jenkins, K. Steinbrenner and D. H. Bent. 1975. SPSS: Statistical Package for The Social Sciences McGraw Hill, New York, 675 p.

Ostle, B. 1963. Statistics in Research. The Iowa State University Press, Ames, Iowa. 585 p.

Poole, R. W. 1974. An Introduction to Quantitative Ecology. McGraw-Hill Book Company, New York. 532 p.

Sneath, P. H. A. and R. R. Sokal. 1973. Numerical Taxonomy. W. H. Freeman and Company, San Francisco. 573 p.

Appendix A

Cumberlandian Mollusk Conservation Program Designated Study Reaches

APPENDIX A

CUMBERLANDIAN MOLLUSK CONSERVATION PROGRAM
DESIGNATED STUDY REACHES

Buffalo River

Stream and Location: Buffalo River below Topsy Bridge, RM 79.9, Lat. 35° 25' 29" N. Long. 87° 42' 30" W., Wayne County, Tennessee (Topsy, Tennessee, Quadrangle Map, 42 NW).

Designated Study Reach: From approximately 300 m to approximately 500 m downstream from the mouth of Mill Creek.

Selected to replace Buffalo RM 102.8, fall 1980.

Stream and Location: Buffalo River along Metal Ford turnout, Natchez Trace Parkway, RM 102.8, Lat, 35° 27' 53" N., Long 87° 28' 42" W., Lewis County, Tennessee (Henryville, Tennessee, Quadrangle Map, 51 NW).

Designated Study Reach: From 50 m downstream to 150 m upstream of the entrance to the former mill race along left bank (historic sign in mill race).

Replaced by Buffalo RM 79.8, fall 1980.

Clinch River

Stream and Location: Clinch River below Kyles Ford, RM 189.5, Lat. 36° 33' 54" N., Long. 83° 02' 29" W., Hancock County, Tennessee (Kyles Ford Tennessee-Virginia, Quadrangle Map, 170 SE).

Designated Study Reach: 200 m upstream from two small stone building supports on right bank approximately 500 ft. upstream from house at sharp bend in road (all downstream from Kyles Ford).

Stream and Location: Clinch River upstream from Virginia Rt. 619 bridge at Fort Blackmore, RM 227.4, Lat, 36° 45' 59" N., Long. 82° 24' 51" W., Scott County, Virginia (Fort Blackmore, Virginia, Quadrangle Map, 187 SE).

Designated Study Reach: 200 m upstream from abutments of new bridge (1973).

Copper Creek

Stream and Location: Copper Creek above Virginia Rt. 627 bridge, CM 1.9, Lat. 36° 39' 25" N., Long. 82° 42' 13" W., Scott County, Virginia (Clinchport, Virginia, Quadrangle Map, 188 NW).

Designated Study Reach: From approximately 100 m to approximately 300 m above Rt. 627 bridge.

Selected to replace Copper Creek RM 7.7, fall 1980.

Stream and Location: Copper Creek at Spivey Mill Dam, RM 7.7, Lat. 36° 39' 42" N., Long. 82° 39' 04" W., Scott County, Virginia (Clinchport, Virginia, Quadrangle Map, 188 NW).

Designated Study Reach: 200 m downstream from the base of the dam.

Replaced by Copper Creek RM 2.9, fall 1980.

Duck River

Stream and Location: Duck River at Sowell Ford, RM 159.4, Lat 35° 35' 30" N., Long. 86° 53' 08" w., Maury County, Tennessee (Glendale, Tennessee, Quadrangle Map, 64 SW).

Designated Study Reach: 200 m downstream from the remnants of a former crib dam located just upstream from the end of the accress road.

Stream and Location: Duck River below Lillard Mill Dam, RM 179.1, Lat. 35° 35' 09" N., Long. 86° 47' 12" W., Marshall County, Tennessee (Verona, Tennessee, Quadrangle Map, 64 SE).

Designated Study REach: From 100 m upstream to 100 m downstream of a large tree (flagged) along the left bank at the upstream side of the access road.

Stream and Location: Duck River just below (former) Halls Mill Dam, RM 202.2, Lat 35° 33' 16" N., Long, 86° 35' 02" W., Bedford County, Tennessee (Unionville, Tennessee, Quadrangle Map, 71 SE).

Designated Study Reach: 200 m downstream from remnants of old mill dam.

Stream and Location: Duck River just downstream from Dement Bridge, RM 243.1, Lat. 35° 27' 59" N., Long. 86° 17' 15" W., Bedford County, Tennessee.

Designated Study Reach: 200 m downstream from the downstream edge of the bridge abutments.

Elk River

Stream and Location: Elk River in Henry Bend, RM 91.4, Lat. 35° 07' 30" N., Long. 86° 32' 59" W., Lincoln County, Tennessee (Fayetteville, Tennessee, 73 NE/Lincoln, Tennessee, 73 SE Quadrangle Maps).

Designated Study Reach: From approximately 600 m to approximately 800 m below the mouth of Wells Creek.

Selected to replace Elk RM 97.0, fall 1980.

Stream and Location: Elk River at Channault Ford, RM 97.0, Lat. 35° 08' 58" N., Long. 86° 30' 40" W., Lincoln County, Tennessee (Fayetteville, Tennessee, Quadrangle Map, 73 NE).

Designated Study Reach: From 100 m upstream to 100 m downstream of rhw mouth of a small tributary that enters along the right bank at the former ford.

Replaced by Elk RM 91.6, fall 1980.

Nolichucky River

Stream and Location: Nolichucky River below Hale Bridge, RM 27.8, Lat. 36° 05' 54" N., Long. 83° 03' 12" W., Greene Country, Tennessee (Parrottsville, Tennessee, Quadrangle Map, 172 SE).

Designated Study Reach: From 150 m downstream to 50 m upstream from the upstream tip of the small island in the left center of the river (not Bewley Island)

North Fork Holston River

Stream and Location: North Fork Holston River at Click Island, RM 6.2, Lat. 36° 35' 52" N., Long. 82° 35' 35" W., Scott County, Virginia (Kingsport, Tennessee-Virginia, Quadrangle Map, 188 SE).

Designated Study Reach: From 100 m downstream to 100 m upstream from downstream tip of island near left bank (more permanently located as even with the most downstream of three apple trees along the pigpen fence line).

Stream and Location: North Fork Holston River above Saltville, RM 85.2, Lat. 36° 53' 55" N., Long. 81° 44' 45" W., Smyth County, Virginia (Broadford, Virginia, Quadrangle Map, 218 NW).

Designated Study Reach: 200 m downstream from a line connecting a large sycamore tree along the road and the right bank (at culvert) to two (adjacent) trees upstream from a multiple-trunk sycamore on the left bank.

Paint Rock River

Stream and Location: Paint Rock River below the mouth of Hurricane Creek RM 60.0 10' 07" W., Jackson County, Alabama (Estill Fork, Alabama-Tennessee, Quadrangle Map, 88 NW).

Designated Study Reach: From approximately 100 m to approximately 300 m below the mouth of Hurricane Creek.

Selected to replace Estill Fork RM 1.5, fall 1980.

Stream and Location: Estill Fork (of Paint Rock River) 0.4 m NE of center of Estill Fork (village), RM 1.5, TIS, Rt. 4E, Lat. 34° 54' 45" N., Long. 86° 09' 50" W., Jackson County, Alabama (Estill Fork, Alabama-Tennessee, Quadrangle Map, 88 NW).

Designated Study Reach: From 100 m upstream to 100 m downstream from the mouth of a short spring-fed creek that enters along the left bank at this site.

Replaced by Paint Rock RM 60.0, fall 1980.

Powell River

Stream and Location: Powell River at Buchanan Ford, RM 99.2, Lat. 36° 33' 30" N., Long. 83° 25' 24" W., Claiborne County, Tennessee (Coleman Gap Tennessee-Virginia, Quadrangle Map, 161 SW).

Designated Study Reach: 200 m downstream from a line joining a large river birch tree (right bank) and a large yellow-popular tree (left bank) just upstream from the old ford.

Stream and Location: Powell River upstream from Fletchers Ford, RM 117.4, Lat. 36° 36' 12" N., Long. 83° 17' 33" W., Lee County, Virginia (Back Valley Tennessee-Virginia, Quadrangle Map, 161 SE).

Designated Study Reach: 200 m upstream from a very large boxelder tree (one trunk curves out over the river) on the right bank just upstream from the former ford.

Appendix B

Summaries of Physical Factors Used in Correlation and Partial Correlation Analyses

Appendix B. Summaries of Physical Factors Used in Correlation and Partial Correlation Analyses

River	Mile	Site Name	Drainage Area (Sq.Mi. - from topo. maps) N	MEAN	MIN	MAX	GRADIENT (Ft./Mi. - from topo. maps) N	MEAN	MIN	MAX	DEPTH (Ft. - from mussel sampling) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford		464				1.9				4.6		
Clinch	189.5	Kyles Ford		1200				2.0				2.9		
Powell	99.2	Buchanan Ford		540				2.5				2.4		
Clinch	227.4	Fort Blackmore		897				6.4				2.5		
Duck	179.1	Lillards Mill		916				1.5				4.1		
Copper Creek	2.1 & 7.7	Copper Creek		131				7.5				2.5		
		Cumberlandian Reaches	6	702.7	131	1268	6	3.63	1.5	7.5	6	3.17	2.4	4.6
Paint Rock	60.0	Estill Fork		99				6.2				3.7		
Duck	159.4	Sowell Ford		1025				1.4				2.1		
Elk	91.4 & 97.0	Elk River		846				1.9				4.1		
N. Fork Holston	85.2	Saltville		221				10.0				2.1		
Holichucky	27.8	Hale Bridge		1289				10.0				4.0		
N. Fork Holston	6.2	Click Island		677				2.2				2.3		
Duck	202.2	Halls Mill		589				1.8				4.9		
Duck	243.1	Dement Bridge		221				4.1				1.5		
Buffalo	79.9	Topsy Bridge		342				3.4				3.8		
		Other Reaches	9	589.9	99	1289	9	4.56	1.4	10.0	0	3.17	1.5	4.1

Appendix B. (Continued)

River	Mile	Site Name	WIDTH (Ft. - ave. at ave. flow) N	MEAN	MIN	MAX	7Q10 (cfs - from historial data) N	MEAN	MIN	MAX	AVERAGE FLOW (cfs - from historical data) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford		148				49				782		
Clinch	189.5	Kyles Ford		287				110				1806		
Powell	99.2	Buchanan Ford		143				64				910		
Clinch	227.4	Fort Blackmore		222				70				1267		
Duck	179.1	Lillards Mill		232				38				1558		
Copper Creek	2.1 & 7.7	Copper Creek		21				21				174		
		Cumberlandian Reaches	6	175.5	21	287	6	58.7	21	110	6	1082.8	174	1806
Paint Rock	60.0	Estill Fork		76				1				216		
Duck	159.4	Sowell Ford		198				32				1714		
Elk	91.4 & 97.0	Elk River		148				136				1495		
N. Fork Holston	85.2	Saltville		88				22				303		
Nolichucky	27.8	Hale Bridge		192				238				2098		
N. Fork Holston	6.2	Click Island		244				56				921		
Duck	202.2	Halls Mill		148				47				1002		
Duck	243.1	Dement Bridge		149				36				386		
Buffalo	79.9	Topsy Bridge		119				86				579		
		Other Reaches	9	151.3	76	244	9	72.7	1	238	9	968.2	216	2098

Appendix B. (Continued)

River	Mile	Site Name	DAILY AVERAGE FLOW (cfs/sq. mi. - calculated) N	MEAN	MIN	MAX	VELOCITY UNDER AVERAGE FLOW (cfs, from flow & vel. data) N	MEAN	MIN	MAX	SUSP. SEDIMENT - AT AVE. FLOW (ppm - from field data) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford		0.754				1.2				42.0		
Clinch	189.5	Kyles Ford		0.710				2.8				43.0		
Powell	99.2	Buchanan Ford		1.065				2.8				72.0		
Clinch	227.4	Fort Blackmore		0.725				3.1				48.0		
Duck	179.1	Lillards Mill		0.546				2.2				15.0		
Copper Creek	2.1 & 7.7	Copper Creek		0.687				1.6				16.0		
		Cumberlandian Reaches	6	0.7478	0 546	1.065	6	2.28	1.2	3.1	6	39.33	15.0	72.0
Paint Rock	60.0	Estill Fork		0.574				1.5				7.0		
Duck	159.4	Sowell Ford		0.537				3.2				26.0		
Elk	91.4 & 97.0	Elk River		0.839				3.1				47.0		
N. Fork Holston	85.2	Saltville		0.679				1.9				21.0		
Nolichucky	27.8	Hale Bridge		1.086				4.3				181.0		
N. Fork Holston	6.2	Click Island		0.628				1.7				78.0		
Duck	202.2	Halls Mill		0.594				2.2				15.0		
Duck	243.1	Dement Bridge		0.814				2.0				19.0		
Buffalo	79.9	Topsy Bridge		1.023				1.6				14.5		
		Other Reaches	9	0.7527	0.537	1.086	9	2.39	1.5	4.3	9	45.38	14.5	181.0

Appendix B. (Continued)

River	Mile	Site Name	AVERAGE VELOCITY (Ft/sec - midchannel ave) N	MEAN	MIN	MAX	20-YEAR RECURRENCE FLOOD (cfs - from historial data) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford		2.6				31000		
Clinch	189.5	Kyles Ford		3.0				52000		
Powell	99.2	Buchanan Ford		3.3				31000		
Clinch	227.4	Fort Blackmore		3.5				38000		
Duck	179.1	Lillards Mill		3.0				39000		
Copper Creek	2.1 & 7.7	Copper Creek		2.2				8500		
		Cumberlandian Reaches	6	2.93	2.2	3.5	6	33250	8500	52000
Paint Rock	60.0	Estill Fork		2.4				16000		
Duck	159.4	Sowell Ford		4.7				41000		
Elk	91.4 & 97.0	Elk River		3.4				24000		
N. Fork Holston	85.2	Saltville		2.3				14000		
Nolichucky	27.8	Hale Bridge		4.6				60000		
N. Fork Holston	6.2	Click Island		2.6				31500		
Duck	202.2	Halls Mill		3.7				32000		
Duck	243.1	Dement Bridge		2.3				7500		
Buffalo	79.9	Topsy Bridge		2.3				43500		
		Other Reaches	9	3.14	2.3	4.7	9	29944.4	7500	32000

Appendix C

Summaries of Chemical Factors Used in Correlation and Partial Correlation Analyses

Appendix C. Summaries of Chemical Factors Used in Correlation and Partial Correlation Analyses

River	Mile	Site Name	ALKALINITY (mg/L) N	MEAN	MIN	MAX	ALUMINUM (µg/L) N	MEAN	MIN	MAX	AMMONIA (mg/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	36	112.72	63.0	140.0	20	1618.00	100.0	14600.0	36	0.03	0.0	0.1
Clinch	189.5	Kyles Ford	18	112.50	14.0	150.0	10	365.00	100.0	2000.0	18	0.03	0.0	0.1
Powell	99.2	Buchanan Ford	36	113.78	61.0	140.0	20	1540.00	100.0	12000.0	36	0.03	0.0	0.1
Clinch	227.4	Fort Blackmore	18	111.89	67.0	130.0	10	421.70	100.0	1300.0	18	0.07	0.0	0.1
Duck	179.1	Lillards Mill	51	79.88	54.0	150.0	30	274.00	20.0	900.0	54	0.04	0.0	0.1
Copper Creek	2.1 & 7.7	Copper Creek	18	173.33	130.0	290.0	10	195.60	50.0	600.0	18	0.03	0.0	0.1
		Cumberlandian Reaches	177	109.53	14.0	290.0	100	812.03	20.0	14600.0	180	0.04	0.0	0.1
Paint Rock	60.0	Estill Fork	13	130.54	97.0	160.0	11	299.82	60.0	1280.0	13	0.06	0.0	0.3
Duck	159.4	Sowell Ford	36	88.72	59.0	160.0	20	247.00	80.0	720.0	36	0.02	0.0	0.0
Elk	91.4 & 97.0	Elk River	18	92.89	69.0	140.0	10	176.80	78.0	450.0	18	0.03	0.0	0.1
N. Fork Holston	85.2	Saltville	17	114.88	56.0	150.0	10	146.80	70.0	300.0	18	0.04	0.0	0.1
Holichucky	27.8	Hale Bridge	18	59.39	29.0	74.0	10	763.00	100.0	4720.0	18	0.03	0.0	0.1
N. Fork Holston	6.2	Click Island	17	101.00	83.0	130.0	10	249.60	100.0	966.0	18	0.03	0.0	0.0
Duck	202.2	Halls Mill	36	63.17	48.0	120.0	20	195.00	90.0	700.0	36	0.04	0.0	0.2
Duck	243.1	Dement Bridge	18	41.94	27.0	66.0	10	201.00	30.0	400.0	18	0.14	0.0	0.3
Buffalo	79.9	Topsy Bridge	20	46.90	30.0	130.0	12	205.83	50.0	800.0	20	0.04	0.0	0.2
		Other Reaches	193	79.11	27.0	160.0	113	265.31	30.0	4720.0	195	0.04	0.0	0.3

Appendix C. (Continued)

River	Mile	Site Name	BOD (5 DAY) (mg/L) N	MEAN	MIN	MAX	CADMIUM (µg/L) N	MEAN	MIN	MAX	CALCIUM (mg/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	36	1.58	1.0	6.0	20	0.17	0.1	0.5	18	34.72	25.5	43.0
Clinch	189.5	Kyles Ford	18	1.42	1.0	6.0	10	0.13	0.1	0.3	10	37.76	29.1	43.0
Powell	99.2	Buchanan Ford	36	1.46	1.0	6.0	20	0.16	0.1	0.3	20	35.93	26.5	44.0
Clinch	227.4	Fort Blackmore	18	1.51	1.0	2.3	10	0.12	0.1	0.3	10	35.60	24.8	43.0
Duck	179.1	Lillards Mill	54	1.36	1.0	2.3	30	0.15	0.1	0.4	30	34.02	16.0	65.2
Copper Creek	2.1 & 7.7	Copper Creek	18	1.45	1.0	2.9	10	0.42	0.1	1.8	10	38.56	26.0	44.0
		Cumberlandian Reaches	180	1.45	1.0	6.0	100	0.18	0.1	1.8	98	35.54	16.0	65.2
Paint Rock	60.0	Estill Fork	13	7.78	1.0	76.0	11	0.50	0.0	2.0	11	53.53	38.4	88.2
Duck	159.4	Sowell Ford	36	1.46	1.0	2.9	20	0.12	0.1	0.3	20	35.43	20.0	60.5
Elk	91.4 & 97.0	Elk River	18	1.27	1.0	2.8	10	0.10	0.1	0.1	10	31.35	23.0	42.6
N. Fork Holston	85.2	Saltville	14	1.52	1.0	3.8	10	0.13	0.1	0.3	10	32.60	16.7	58.0
Holichucky	27.8	Hale Bridge	18	1.79	1.0	5.9	10	0.14	0.1	0.3	10	18.86	12.2	22.0
N. Fork Holston	6.2	Click Island	17	1.41	1.0	3.5	10	0.12	0.1	0.2	10	50.24	35.4	70.0
Duck	202.2	Halls Mill	36	1.22	1.0	1.6	20	0.13	0.1	0.3	20	26.45	1.7	49.7
Duck	243.1	Dement Bridge	18	1.58	1.0	2.2	10	0.10	0.1	0.1	10	15.41	12.0	20.7
Buffalo	79.9	Topsy Bridge	20	1.88	1.0	7.4	12	0.47	0.1	1.4	12	14.62	11.1	24.0
		Other Reaches	190	1.91	1.0	76.0	113	0.20	0.0	2.0	113	30.85	1.7	88.2

Appendix C. (Continued)

River	Mile	Site Name	CHLORIDE (mg/L) N	MEAN	MIN	MAX	CHROMIUM (µg/L) N	MEAN	MIN	MAX	CONDUCTIVITY (Microhms) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	36	4.72	3.0	8.0	20	4.60	1.0	34.0	36	333.61	35.0	440.0
Clinch	189.5	Kyles Ford	18	7.83	5.0	12.0	10	1.90	1.0	8.0	18	313.33	240.0	360.0
Powell	99.2	Buchanan Ford	36	4.83	3.0	7.0	20	1.70	1.0	6.0	36	332.22	200.0	390.0
Clinch	227.4	Fort Blackmore	17	8.35	1.0	12.0	10	1.10	1.0	2.0	18	340.00	210.0	440.0
Duck	179.1	Lillards Mill	54	5.17	3.0	10.0	30	1.80	1.0	7.0	150	169.48	12.0	350.0
Copper Creek	2.1 & 7.7	Copper Creek	18	4.22	3.0	6.0	10	1.10	1.0	2.0	18	317.22	250.0	390.0
		Cumberlandian Reaches	179	5.49	1.0	12.0	100	2.21	1.0	34.0	276	242.25	12.0	440.0
Paint Rock	60.0	Estill Fork	13	2.69	2.0	6.0	11	1.09	1.0	2.0	15	266.67	110.0	360.0
Duck	159.4	Sowell Ford	36	4.94	3.0	10.0	20	1.20	1.0	3.0	92	180.15	9.0	370.0
Elk	91.4 & 97.0	Elk River	18	3.61	3.0	5.0	10	1.50	1.0	5.0	50	168.86	10.0	290.0
N. Fork Holston	85.2	Saltville	18	3.94	2.0	12.0	10	1.10	1.0	2.0	18	246.11	140.0	320.0
Nolichucky	27.8	Hale Bridge	18	3.11	3.0	4.0	10	2.40	1.0	12.0	16	153.13	70.0	180.0
N. Fork Holston	6.2	Click Island	18	90.67	3.0	180.0	10	1.30	1.0	4.0	18	566.11	220.0	850.0
Duck	202.2	Halls Mill	36	4.00	3.0	7.0	20	1.10	1.0	2.0	88	145.52	5.0	300.0
Duck	243.1	Dement Bridge	18	2.39	1.0	4.0	10	1.00	1.0	1.0	53	108.72	3.0	160.0
Buffalo	79.9	Topsy Bridge	20	3.25	1.0	12.0	12	2.67	1.0	21.0	32	81.91	31.0	120.0
		Other Reaches	195	11.74	1.0	180.0	113	1.44	1.0	21.0	382	176.12	3.0	50.0

Appendix C. (Continued)

River	Mile	Site Name	COD (mg/L) N	COD (mg/L) MEAN	COD (mg/L) MIN	COD (mg/L) MAX	COPPER (µg/L) N	COPPER (µg/L) MEAN	COPPER (µg/L) MIN	COPPER (µg/L) MAX	DISSOLVED OXYGEN (mg/L) N	DISSOLVED OXYGEN (mg/L) MEAN	DISSOLVED OXYGEN (mg/L) MIN	DISSOLVED OXYGEN (mg/L) MAX
Powell	117.4	Fletcher Ford	36	11.50	3.0	92.0	20	9.56	1.0	20.0	36	9.03	7.3	12.1
Clinch	189.5	Kyles Ford	18	6.50	4.0	13.0	10	10.30	1.0	20.0	18	8.93	6.6	14.4
Powell	99.2	Buchanan Ford	36	8.78	2.0	59.0	20	11.47	1.0	30.0	34	8.69	6.8	12.9
Clinch	227.4	Fort Blackmore	15	13.27	5.0	92.0	10	10.30	1.0	20.0	18	8.84	5.9	19.0
Duck	179.1	Lillards Mill	54	7.72	6.0	12.0	30	9.79	1.0	20.0	156	8.19	4.4	13.5
Copper Creek	2.1 & 7.7	Copper Creek	18	5.39	1.0	12.0	10	10.30	1.0	30.0	18	9.57	7.1	19.7
		Cumberlandian Reaches	177	8.81	1.0	92.0	100	10.23	1.0	30.0	280	8.54	4.4	19.7
Paint Rock	60.0	Estill Fork	13	11.31	5.0	27.0	11	14.09	1.0	50.0	15	8.42	6.2	11.0
Duck	159.4	Sowell Ford	36	7.94	5.0	12.0	20	11.26	1.0	30.0	104	8.16	3.2	12.9
Elk	91.4 & 97.0	Elk River	18	5.78	4.0	9.0	10	11.25	1.0	30.0	52	8.16	5.7	12.0
N. Fork Holston	85.2	Saltville	18	6.17	2.0	13.0	10	10.30	1.0	30.0	16	9.19	7.0	14.0
Nolichucky	27.8	Hale Bridge	18	6.78	2.0	29.0	10	11.30	1.0	30.0	16	9.23	7.0	15.7
N. Fork Holston	6.2	Click Island	18	8.11	6.0	17.0	10	16.60	1.0	40.0	17	9.68	6.3	15.6
Duck	202.2	Halls Mill	36	8.39	5.0	12.0	20	12.00	1.0	40.0	92	7.24	2.7	12.9
Duck	243.1	Dement Bridge	18	7.94	6.0	12.0	10	10.60	1.0	30.0	55	8.62	3.7	13.6
Buffalo	79.9	Topsy Bridge	20	5.80	2.0	14.0	12	9.17	1.0	30.0	32	7.57	3.5	12.0
		Other Reaches	195	7.57	2.0	29.0	113	11.78	1.0	50.0	399	8.13	2.7	15.7

Appendix C. (Continued)

River	Mile	Site Name	HARDNESS (mg/L) N	MEAN	MIN	MAX	IRON (DISSOLVED) (µg/L) N	MEAN	MIN	MAX	IRON (TOTAL) (µg/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	36	151.06	89.0	180.0	20	45.15	5.5	80.0	20	2534.40	97.0	23000.0
Clinch	189.5	Kyles Ford	18	148.89	110.0	190.0	10	63.60	5.0	210.0	10	536.70	50.0	2700.0
Powell	99.2	Buchanan Ford	36	149.78	96.0	170.0	20	56.46	15.0	140.0	20	2108.44	51.4	18000.0
Clinch	227.4	Fort Blackmore	18	148.22	88.0	190.0	10	47.40	5.0	70.0	10	448.20	50.0	970.0
Duck	179.1	Lillards Mill	54	84.94	56.0	180.0	27	50.03	9.3	100.0	30	442.99	95.9	860.0
Copper Creek	2.1 & 7.7	Copper Creek	18	157.22	140.0	170.0	9	59.56	21.0	85.0	10	1030.40	40.0	7600.0
		Cumberlandian Reaches	180	131.08	56.0	190.0	96	52.39	5.0	210.0	100	1262.99	40.0	23000.0
Paint Rock	60.0	Estill Fork	10	146.50	110.0	190.0	11	49.55	5.0	150.0	11	347.45	60.0	1900.0
Duck	159.4	Sowell Ford	36	92.17	65.0	170.0	18	48.56	11.0	130.0	20	346.70	80.0	654.0
Elk	91.4 & 97.0	Elk River	18	92.89	70.0	130.0	9	33.98	8.0	50.0	10	243.30	100.0	408.0
N. Fork Holston	85.2	Saltville	18	126.44	69.0	160.0	10	85.00	13.0	350.0	10	231.00	70.0	440.0
Nolichucky	27.8	Hale Bridge	18	66.67	44.0	76.0	10	72.00	36.0	170.0	10	987.70	50.0	6600.0
N. Fork Holston	6.2	Click Island	18	173.33	110.0	240.0	10	43.50	10.0	60.0	10	361.70	10.0	1200.0
Duck	202.2	Halls Mill	36	74.33	52.0	140.0	20	85.20	5.0	210.0	20	394.90	90.0	880.0
Duck	243.1	Dement Bridge	18	46.89	40.0	63.0	10	168.00	10.0	560.0	10	545.20	80.0	1200.0
Buffalo	79.9	Topsy Bridge	14	44.79	33.0	57.0	11	64.18	50.0	150.0	12	230.75	110.0	463.0
		Other Reaches	186	92.46	33.0	240.0	109	71.74	5.0	560.0	113	399.22	10.0	6600.0

Appendix C. (Continued)

River	Mile	Site Name	LEAD (µg/L) N	LEAD (µg/L) MEAN	LEAD (µg/L) MIN	LEAD (µg/L) MAX	MANGANESE (DISSOLVED) (µg/L) N	MANGANESE (DISSOLVED) (µg/L) MEAN	MANGANESE (DISSOLVED) (µg/L) MIN	MANGANESE (DISSOLVED) (µg/L) MAX	MANGANESE (TOTAL) (µg/L) N	MANGANESE (TOTAL) (µg/L) MEAN	MANGANESE (TOTAL) (µg/L) MIN	MANGANESE (TOTAL) (µg/L) MAX
Powell	117.4	Fletcher Ford	20	6.00	1.0	28.0	20	33.89	5.9	90.0	20	182.04	10.0	1400.0
Clinch	189.5	Kyles Ford	10	3.60	1.0	10.0	10	27.20	5.0	100.0	10	55.80	10.0	170.0
Powell	99.2	Buchanan Ford	20	4.10	1.0	12.0	20	19.45	8.5	40.0	20	158.85	8.5	1100.0
Clinch	227.4	Fort Blackmore	10	2.80	1.0	9.0	10	35.60	5.0	80.0	10	61.80	10.0	120.0
Duck	179.1	Lillards Mill	30	3.10	1.0	8.0	27	27.87	6.8	60.0	30	51.00	18.0	116.0
Copper Creek	2.1 & 7.7	Copper Creek	10	2.20	1.0	9.0	9	25.11	9.0	60.0	10	37.60	5.0	80.0
		Cumberlandian Reaches	100	3.81	1.0	28.0	96	27.85	5.0	100.0	100	99.00	5.0	1400.0
Paint Rock	60.0	Estill Fork	11	2.45	1.0	7.0	11	38.64	5.0	130.0	11	72.25	20.0	220.0
Duck	159.4	Sowell Ford	20	5.60	1.0	41.0	18	11.21	5.0	20.0	20	42.44	10.0	80.0
Elk	91.4 & 97.0	Elk River	10	1.90	1.0	3.0	9	43.57	10.0	190.0	10	138.10	30.0	330.0
N. Fork Holston	85.2	Saltville	10	3.20	1.0	13.0	10	36.30	8.0	220.0	10	28.30	10.0	60.0
Nolichucky	27.8	Hale Bridge	10	3.60	1.0	17.0	10	32.50	10.0	100.0	10	80.90	10.0	370.0
N. Fork Holston	6.2	Click Island	10	3.20	1.0	9.0	10	14.30	5.0	30.0	10	26.20	5.0	60.0
Duck	202.2	Halls Mill	20	3.80	1.0	16.0	20	23.90	10.0	44.0	20	60.90	40.0	100.0
Duck	243.1	Dement Bridge	10	4.20	1.0	18.0	10	373.20	30.0	950.0	10	589.30	130.0	1200.0
Buffalo	79.9	Topsy Bridge	12	3.25	1.0	9.0	11	22.45	10.0	51.0	12	49.63	19.5	100.0
		Other Reaches	113	3.67	1.0	41.0	109	57.86	5.0	950.0	113	106.95	5.0	1200.0

Appendix C. (Continued)

River	Mile	Site Name	MERCURY (µg/L) N	MEAN	MIN	MAX	NITROGEN (ORGANIC) (mg/L) N	MEAN	MIN	MAX	NO_2 & NO_3 (mg/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	20	0.20	0.2	0.2	36	0.13	0.0	0.3	36	0.57	0.1	1.0
Clinch	189.5	Kyles Ford	10	0.20	0.2	0.2	18	0.13	0.0	0.3	18	0.37	0.0	0.9
Powell	99.2	Buchanan Ford	20	0.22	0.2	0.4	36	0.13	0.0	0.3	36	0.47	0.0	1.2
Clinch	227.4	Fort Blackmore	10	0.20	0.2	0.2	18	0.15	0.0	0.3	18	0.42	0.0	1.5
Duck	179.1	Lillards Mill	30	0.20	0.2	0.2	54	0.15	0.0	0.3	54	0.72	0.2	2.6
Copper Creek	2.1 & 7.7	Copper Creek	10	0.24	0.2	0.6	18	0.09	0.0	0.2	18	0.49	0.2	1.2
		Cumberlandian Reaches	100	0.21	0.2	0.6	180	0.13	0.0	0.3	180	0.55	0.0	2.6
Paint Rock	60.0	Estill Fork	9	0.22	0.2	0.4	13	0.30	0.1	0.7	13	0.15	0.0	0.4
Duck	159.4	Sowell Ford	20	0.29	0.2	1.0	36	0.18	0.1	0.5	36	0.67	0.3	2.2
Elk	91.4 & 97.0	Elk River	10	0.23	0.2	0.4	18	0.13	0.0	0.3	18	0.59	0.3	1.2
N. Fork Holston	85.2	Saltville	10	0.24	0.2	0.6	18	0.10	0.0	0.4	18	0.60	0.3	1.4
Nolichucky	27.8	Hale Bridge	10	0.20	0.2	0.2	18	0.14	0.0	0.4	18	0.51	0.2	1.0
N. Fork Holston	6.2	Click Island	10	0.20	0.0	0.4	15	0.14	0.0	0.2	18	0.28	0.0	1.3
Duck	202.2	Halls Mill	20	0.21	0.2	0.3	36	0.17	0.1	0.2	36	0.59	0.2	1.4
Duck	243.1	Dement Bridge	10	0.20	0.2	0.2	18	0.17	0.1	0.3	18	0.32	0.2	0.8
Buffalo	79.9	Topsy Bridge	11	0.20	0.2	0.2	20	0.15	0.0	0.6	20	0.27	0.0	0.6
		Other Reaches	110	0.23	0.0	1.0	192	0.16	0.0	0.7	195	0.48	0.0	2.2

Appendix C. (Continued)

River	Mile	Site Name	pH (H+)				PHOSPHORUS (TOTAL) (ug/L)				RESIDUE (TOTAL) (ug/L)			
			N	MEAN	MIN	MAX	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	36	7.79	7.1	8.3	36	0.04	0.0	0.3	36	209.44	110.0	260.0
Clinch	189.5	Kyles Ford	18	7.68	7.3	8.0	18	0.02	0.0	0.1	18	171.11	100.0	210.0
Powell	99.2	Buchanan Ford	36	7.76	7.1	8.3	36	0.03	0.0	0.2	36	188.33	120.0	210.0
Clinch	227.4	Fort Blackmore	18	7.69	7.3	8.4	18	0.03	0.0	0.1	18	213.94	91.0	620.0
Duck	179.1	Lillards Mill	156	7.76	4.8	9.1	54	0.13	0.0	0.2	54	101.11	50.0	210.0
Copper Creek	2.1 & 7.7	Copper Creek	18	7.78	7.2	8.5	18	0.01	0.0	0.0	18	167.78	150.0	200.0
		Cumberlandian Reaches	282	7.76	4.8	9.1	180	0.06	0.0	0.3	180	165.17	50.0	620.0
Paint Rock	60.0	Estill Fork	15	7.33	5.7	8.1	13	0.07	0.0	0.5	13	163.08	90.0	200.0
Duck	169.4	Sowell Ford	104	7.85	6.2	8.2	36	0.20	0.1	1.6	36	112.22	80.0	200.0
Elk	91.4 & 97.0	Elk River	52	8.06	7.3	9.6	18	0.05	0.0	0.4	18	97.78	60.0	140.0
N. Fork Holston	85.2	Saltville	17	7.58	6.8	8.1	18	0.02	0.0	0.0	18	135.00	80.0	180.0
Nolichucky	27.8	Hale Bridge	18	7.29	6.7	7.8	18	0.07	0.0	0.2	18	100.28	55.0	160.0
N. Fork Holston	6.2	Click Island	17	7.67	7.3	8.1	15	0.02	0.0	0.0	18	322.22	140.0	470.0
Duck	202.2	Halls Mill	90	7.72	7.2	8.3	36	0.14	0.0	0.2	36	95.00	70.0	200.0
Duck	243.1	Dement Bridge	55	7.94	7.0	9.5	18	0.05	0.0	0.1	15	56.73	1.0	80.0
Buffalo	79.9	Topsy Bridge	32	7.22	4.8	8.3	20	0.05	0.0	0.3	20	64.50	20.0	300.0
		Other Reaches	400	7.75	4.8	9.6	192	0.09	0.0	1.6	192	122.48	1.0	470.0

Appendix C. (Continued)

River	Mile	Site Name	RESIDUE (DISSOLVED) (mg/L) N	MEAN	MIN	MAX	SELENIUM (µg/L) N	MEAN	MIN	MAX	SODIUM (mg/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	36	48.50	2.0	720.0	20	1.20	1.0	2.0	20	11.46	5.1	18.0
Clinch	189.5	Kyles Ford	18	15.56	1.0	80.0	10	2.20	1.0	13.0	10	6.15	2.7	8.7
Powell	99.2	Buchanan Ford	36	37.39	3.0	500.0	20	1.10	1.0	2.0	20	8.84	4.5	12.0
Clinch	227.4	Fort Blackmore	18	20.00	1.0	35.0	10	1.00	1.0	1.0	10	7.45	2.2	11.0
Duck	179.1	Lillards Mill	54	11.17	4.0	17.0	30	1.10	1.0	2.0	30	2.57	1.9	3.5
Copper Creek	2.1 & 7.7	Copper Creek	18	7.44	1.0	13.0	10	1.00	1.0	1.0	10	1.78	1.0	2.7
		Cumberlandian Reaches	180	24.83	1.0	720.0	100	1.21	1.0	13.0	100	6.37	1.0	18.0
Paint Rock	60.0	Estill Fork	13	8.23	1.0	45.0	9	1.00	1.0	1.0	10	1.33	0.8	2.3
Duck	159.4	Sowell Ford	36	17.44	4.0	83.0	20	1.00	1.0	1.0	20	2.41	1.6	3.1
Elk	91.4 & 97.0	Elk River	18	6.56	2.0	13.0	10	1.00	1.0	1.0	10	1.42	0.9	1.8
N. Fork Holston	85.2	Saltville	18	6.89	1.0	13.0	10	1.00	1.0	1.0	10	1.59	1.0	2.0
Holichucky	27.8	Hale Bridge	18	23.78	2.0	150.0	10	1.00	1.0	1.0	10	2.45	1.3	3.1
N. Fork Holston	6.2	Click Island	18	7.11	1.0	27.0	10	1.30	1.0	4.0	10	35.71	13.2	75.0
Duck	202.2	Halls Mill	36	11.94	3.0	17.0	20	1.00	1.0	1.0	20	2.12	0.1	3.2
Duck	243.1	Dement Bridge	18	10.00	5.0	18.0	10	1.00	1.0	1.0	10	1.21	0.9	1.6
Buffalo	79.9	Topsy Bridge	20	11.45	1.0	63.0	11	1.00	1.0	1.0	12	1.15	0.9	1.7
		Other Reaches	195	12.16	1.0	150.0	110	1.03	1.0	4.0	112	4.84	0.1	75.0

Appendix C. (Continued)

River	Mile	Site Name	SULFATE (mg/L) N	MEAN	MIN	MAX	TEMPERATURE (° C) N	MEAN	MIN	MAX	TOC (mg/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	30	55.73	31.0	80.0	34	16.41	3.0	24.0	36	3.08	1.6	14.0
Clinch	189.5	Kyles Ford	18	31.56	18.0	42.0	17	17.44	3.0	25.0	18	2.58	1.8	3.6
Powell	99.2	Buchanan Ford	30	47.33	31.0	56.0	34	16.74	3.0	24.0	36	2.96	1.6	8.0
Clinch	227.4	Fort Blackmore	18	39.22	14.0	54.0	18	15.89	0.0	26.0	17	3.08	2.1	4.7
Duck	179.1	Lillards Mill	51	8.35	5.0	24.0	156	21.42	1.3	33.3	54	3.42	1.7	5.7
Copper Creek	2.1 & 7.7	Copper Creek	18	7.39	4.0	26.0	15	16.90	8.0	23.0	17	2.32	1.7	4.0
		Cumberlandian Reaches	165	29.85	4.0	80.0	274	19.36	0.0	33.3	178	3.03	1.6	14.0
Paint Rock	60.0	Estill Fork	13	18.31	9.0	30.0	25	18.05	9.0	28.5	13	4.22	2.3	8.1
Duck	159.4	Sowell Ford	36	9.22	2.0	21.0	104	20.99	0.6	32.5	36	3.46	2.1	4.8
Elk	91.4 & 97.0	Elk River	18	6.94	3.0	12.0	52	17.33	3.7	29.1	18	2.80	1.9	4.4
N. Fork Holston	85.2	Saltville	18	10.51	4.0	15.0	16	16.46	3.1	24.0	18	2.84	1.7	7.8
Nolichucky	27.8	Hale Bridge	18	8.61	6.0	29.0	18	18.23	1.5	29.5	17	2.65	1.3	7.0
N. Fork Holston	6.2	Click Island	18	25.17	15.0	39.0	16	18.66	4.5	26.0	15	3.05	1.5	6.4
Duck	202.2	Halls Mill	34	7.12	4.0	17.0	92	17.91	0.5	29.8	36	3.51	2.4	5.6
Duck	243.1	Dement Bridge	17	4.41	3.0	6.0	55	14.65	3.8	22.2	18	3.53	2.0	7.1
Buffalo	79.9	Topsy Bridge	20	3.05	1.0	7.0	56	18.54	5.5	25.7	20	2.81	1.1	8.0
		Other Reaches	192	9.74	1.0	39.0	434	18.24	0.5	32.5	191	3.24	1.1	8.1

Appendix C. (Continued)

River	Mile	Site Name	ZINC (ug/L) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	20	30.50	5.0	188.0
Clinch	189.5	Kyles Ford	10	10.00	5.0	20.0
Powell	99.2	Buchanan Ford	20	32.26	1.6	188.0
Clinch	227.4	Fort Blackmore	10	15.10	5.0	40.0
Duck	179.1	Lillards Mill	30	26.34	1.4	160.0
Copper Creek	2.1 & 7.7	Copper Creek	10	20.50	10.0	58.0
		Cumberlandian Reaches	100	25.01	1.4	188.0
Paint Rock	60.0	Estill Fork	11	122.09	5.0	1190.0
Duck	159.4	Sowell Ford	20	7.70	2.0	10.0
Elk	91.4 & 97.0	Elk River	10	17.17	5.0	90.7
N. Fork Holston	85.2	Saltville	10	22.90	5.0	140.0
Holichucky	27.4	Hale Bridge	10	21.70	5.0	83.0
N. Fork Holston	6.2	Click Island	10	38.30	5.0	130.0
Duck	202.2	Halls Mill	20	15.90	8.0	42.0
Duck	243.1	Dement Bridge	10	16.80	3.0	80.0
Buffalo	79.9	Topsy Bridge	12	72.25	5.0	599.0
		Other Reaches	113	34.08	2.0	1190.0

Appendix D. (Continued)

River	Mile	Site Name	PHYTOPLANKTON TAXA (Genera) N	MEAN	MIN	MAX	PERIPHYTON DENSITY (No/cm^2 x 10^3) N	MEAN	MIN	MAX	PERIPHYTON TAXA (Genera) N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	32	10.09	4.0	17.0	14	325.11	61.6	789.4	14	13.50	10.0	17.0
Clinch	189.5	Kyles Ford	32	9.50	4.0	15.0	15	508.73	1.3	2100.8	15	12.73	6.0	18.0
Powell	99.2	Buchanan Ford	31	10.19	5.0	16.0	15	272.74	25.2	520.1	15	12.20	8.0	22.0
Clinch	227.4	Fort Blackmore	32	12.28	5.0	24.0	15	257.74	26.4	1031.2	15	13.60	9.0	20.0
Duck	179.1	Lillards Mill	32	13.00	0.0	24.0	15	1832.71	46.5	10341.9	15	11.53	5.0	17.0
Copper Creek	2.1 & 7.7	Copper Creek	32	9.50	5.0	21.0	15	262.00	5.0	1407.7	15	13.87	7.0	23.0
		Cumberlandian Reaches	191	10.76	0.0	24.0	89	579.33	1.3	10341.9	89	12.90	5.0	23.0
Paint Rock	60.0	Estill Fork	36	9.92	2.0	26.0	15	720.56	9.8	1431.8	15	15.20	8.0	24.0
Duck	159.4	Sowell Ford	32	8.31	0.0	16.0	15	455.39	30.9	2677.9	15	10.07	4.0	19.0
Elk	91.4 & 97.0	Elk River	28	9.14	0.0	20.0	15	270.89	56.5	769.1	15	13.60	9.0	20.0
N. Fork Holston	85.0	Saltville	32	8.72	4.0	15.0	15	480.79	3.2	1775.2	15	12.33	4.0	17.0
Nolichucky	27.8	Hale Bridge	32	15.66	6.0	40.0	15	245.69	55.2	708.4	15	13.20	8.0	21.0
N. Fork Holston	6.2	Click Island	32	9.19	4.0	19.0	15	184.35	8.1	245.6	15	10.80	9.0	14.0
Duck	202.2	Halls Mill	32	8.28	3.0	14.0	15	360.31	5.3	2066.0	15	8.87	3.0	14.0
Duck	243.1	Dement Bridge	32	14.56	7.0	25.0	15	147.85	12.3	541.4	15	10.80	5.0	18.0
Buffalo	79.9	Topsy Bridge	36	8.03	3.0	14.0	15	493.14	36.3	1428.2	15	11.67	9.0	14.0
		Other Reaches	292	10.13	0.0	40.0	135	364.33	3.2	2677.9	135	11.84	3.0	24.0

Appendix D. (Continued)

River	Mile	Site Name	BENTHIC DENSITY (No/ft^2)				BENTHIC TAXA (Genera)				FISH DENSITY (No/Transect)			
			N	MEAN	MIN	MAX	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	16	1654.38	382.0	7374.0	16	13.19	7.0	19.0	3	38.11	19.9	65.9
Clinch	189.5	Kyles Ford	16	1323.88	369.0	3088.0	16	15.56	10.0	24.0	3	8.62	4.3	16.2
Powell	99.2	Buchanan Ford	16	1910.44	0.0	6661.0	16	13.13	0.0	21.0	3	25.41	13.0	43.7
Clinch	227.4	Fort Blackmore	16	3186.63	0.0	20086.0	16	17.75	0.0	27.0	3	28.75	24.7	34.7
Duck	179.1	Lillards Mill	16	575.31	53.0	1767.0	16	9.63	2.0	20.0	3	19.33	13.9	28.9
Copper Creek	2.1 & 7.7	Copper Creek	20	1807.65	397.0	9010.0	20	15.50	8.0	22.0	3	19.96	16.9	25.3
		Cumberlandian Reaches	100	1745.63	0.0	20086.0	100	14.18	0.0	27.0	18	23.36	4.3	65.9
Paint Rock	60.0	Estill Fork	20	727.45	20.0	5944.0	20	12.70	2.0	31.0	3	11.03	7.5	13.2
Duck	159.4	Sowell Ford	12	498.33	0.0	1056.0	12	10.00	0.0	18.0	3	24.88	18.0	33.4
Elk	91.4 & 97.0	Elk River	16	233.56	20.0	758.0	16	6.50	2.0	11.0	3	13.41	12.7	14.8
N. Fork Holston	85.2	Saltville	16	1803.56	103.0	3195.0	16	18.19	7.0	25.0	3	13.76	12.9	14.4
Nolichucky	27.8	Hale Bridge	16	3115.56	252.0	12258.0	16	13.75	10.0	23.0	3	35.81	31.5	41.9
N. Fork Holston	6.2	Click Island	16	2592.13	550.0	17494.0	16	18.56	11.0	26.0	3	22.04	11.2	39.5
Duck	202.2	Halls Mill	16	446.75	71.0	881.0	16	10.88	4.0	22.0	3	4.93	4.7	5.1
Duck	243.1	Dement Bridge	16	441.88	50.0	2444.0	16	7.88	4.0	16.0	3	7.08	4.7	8.4
Buffalo	79.9	Topsy Bridge	20	925.85	61.0	4680.0	20	13.05	5.0	22.0	3	8.69	6.7	11.4
		Other Reaches	148	1197.17	0.0	17494.0	148	12.48	0.0	31.0	27	15.74	4.7	41.9

Appendix D. (Continued)

River	Mile	Site Name	FISH TAXA (Species)				ZOOPLANKTON DENSITY (No/m²)				ZOOPLANKTON TAXA (Genera)			
			N	MEAN	MIN	MAX	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX
Powell	117.4	Fletcher Ford	3	39.33	37.0	42.0	16	399.94	0.0	953.0	16	3.88	0.0	8.0
Clinch	189.5	Kyles Ford	3	45.67	44.0	47.0	16	451.06	0.0	1087.0	16	4.06	0.0	13.0
Powell	99.2	Buchanan Ford	3	40.33	38.0	44.0	16	601.56	0.0	2240.0	16	4.69	0.0	10.0
Clinch	227.4	Fort Blackmore	3	38.67	35.0	43.0	16	788.44	0.0	4296.0	16	4.94	0.0	10.0
Duck	179.1	Lillards Mill	3	49.33	47.0	52.0	16	1693.50	369.0	3695.0	16	8.94	4.0	14.0
Copper Creek	2.1 & 7.7	Copper Creek	3	36.33	35.0	37.0	16	622.50	0.0	2090.0	16	4.00	0.0	9.0
		Cumberlandian Reaches	18	41.61	35.0	52.0	96	759.50	0.0	4296.0	96	5.08	0.0	14.0
Paint Rock	60.0	Estill Fork	3	38.33	34.0	41.0	18	5073.44	0.0	26681.0	18	7.89	0.0	23.0
Duck	159.4	Sowell Ford	3	38.67	35.0	43.0	16	642.75	84.0	2240.0	16	5.69	1.0	14.0
Elk	91.4 & 97.0	Elk River	3	33.00	28.0	36.0	14	1944.86	0.0	9136.0	14	5.29	0.0	11.0
N. Fork Holston	95.2	Saltville	3	25.00	21.0	27.0	16	978.50	84.0	4359.0	16	5.63	1.0	11.0
Nolichucky	27.8	Hale Bridge	3	30.00	27.0	32.0	16	1182.75	0.0	7249.0	16	5.31	0.0	15.0
N. Fork Holston	6.2	Click Island	3	32.00	30.0	35.0	16	589.00	0.0	2726.0	16	4.06	0.0	11.0
Duck	202.2	Halls Mill	3	35.33	27.0	43.0	16	1004.25	0.0	5102.0	16	6.69	0.0	23.0
Duck	243.1	Dement Bridge	3	24.33	19.0	31.0	16	5505.00	84.0	42588.0	16	7.44	1.0	15.0
Buffalo	79.9	Topsy Bridge	3	47.67	44.0	50.0	18	461.67	0.0	1940.0	18	4.11	0.0	10.0
		Other Reaches	27	33.81	19.0	50.0	146	1954.08	0.0	42588.0	146	5.80	0.0	23.0